DIRECTION AND POSITION FINDING BY WIRELESS

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Illustrated with over 250 Photographs and Diagrams

LONDON:
THE WIRELESS PRESS, LIMITED
12 & 13, HENRIETTA STREET, STRAND, W.C.2
NEW YORK: WIRELESS PRESS INC., 326 Broadway

1922

PREFACE.

MANY text books on the general subject of wireless telegraphy have a section dealing with Directional Reception and Direction Finding, but in almost every case the information is of an academic nature and treats rather of the theoretical circuits used and the history of this special branch of the art—matters of undoubted importance and interest under certain circumstances. There seems now, however, to be an increasing demand for a book dealing not only with the principles of the subject, but also with the constructional details of direction finding installations for shore service and for the navigation of ships and aircraft; also with such subjects as the use of special maps for D.F. work, the freak phenomena which cause errors in bearings, the elimination of faults peculiar to the D.F. receiver, etc., all of which play an important part in the practical operation of the D.F. station. An attempt has therefore been made to describe the principles and practice of Direction and Position Finding in this country in such a way that the subject may be grasped easily by the engineer tackling this field of wireless work for the first time, the radio-telegraphist in charge of a direction finding installation or the general student of wireless telegraphy.

Except in the Introduction and in cases where it was necessary for purposes of identification, names have not been introduced into the text, but numbers referring to the Bibliography are quoted in many cases, enabling the reader to consult the correct authority in connection with various theories, experiments, etc., which are mentioned.

In order to make the instructions on the use of the D.F. receiving apparatus as complete as possible, a chapter has been included concerning the thermionic valve. This chapter has been made very brief and is intended principally as an aid to the proper use and maintenance of the valve circuits employed in the amplifiers described in subsequent parts of the book. Many text books, devoted solely to valves and valve circuits, are published and these should be consulted for further information on the subject. The latter part of Chapter V, dealing with Position Finding by Cross Bearings, explains the way in which navigation is carried out by means of a D.F. installed in a ship, and may be of some value to the sea-going radio-telegraphist who, whilst not in any way responsible for the plotting of the D.F. bearings, may possibly with the aid of this information, be enabled to make more intelligent use of his installation. To the navigating officer reading this chapter nothing of any novelty will be found, although the possibilities of the wireless D.F. for emergency or checking purposes

may become more apparent. In dealing with the actual Construction of Apparatus and Installation of the Shore and Ship Stations, in Chapters VII and VIII, the Marconi-Bellini-Tosi System has been described as being the more commonly used system in this country. The Simple Rotating Frame D.F. is popular in America and France but has never been employed to any extent in England.

The number of aeroplanes which have had D.F. apparatus installed up to the present time (outside the Services) is comparatively small, but a chapter is included which states the main problems of the Aircraft D.F. and includes the Wing Coil System, the Marconi-Bellini-Tosi and the Robinson or Royal Air Force Systems. In connection with the last mentioned, thanks are due to Captain J. Robinson for supplying photographs of his apparatus, and to the British Air Ministry for permission to publish them; also to the United States Navy Bureau, Washington, for permission to reproduce the illustration shown in Fig. 233, and the Institute of Radio Engineers, in the journal of which Society the illustration appeared.

Such a large proportion of the information contained in the book has resulted from discussions between, or the experiences of members of the Marconi Research Staff, that it is no easy matter to make the proper acknowledgements, but the author has to pay tribute to the vast amount of work on the subject by Captain H. J. Round, whose paper on "Direction and Position Finding" (Ref. 19), is well known to wireless readers; also to Mr. G. M. Wright, Mr. T. L. Eckersley and Mr. S. B. Smith, also the authors of numerous books and published articles which have been consulted. The author wishes particularly to record his very grateful thanks to Mr. G. M. Wright, with whom he originally intended to collaborate in the writing of the book. Unfortunately, absence abroad and other reasons, prevented Mr. Wright actually sharing authorship, but the present writer is greatly in his debt for valuable help and criticism received throughout the preparation of the manuscript, for the bulk of Chapters II and III, practically as printed, and for subsequent help in reading the proofs. Thanks are also due to Mr. J. N. Johnson for extensive contributions to Chapter VIII; to Mr. F. P. Swann and Mr. J. M. Furnival for criticism and for reading sections of the proofs; to the Marconi Company for the supply of and permission to reproduce a number of photographs of their apparatus; to the Lords Commissioners of the British Admiralty for permission to reproduce certain of their publications (acknowledged in the text) and finally, to the staff of the Wireless Press for their skill in interpreting the author's sketches and diagrams.

R. KEEN.

Chelmsford, *August*, 1922.

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CHAPTER 1.

INTRODUCTION.

Numbers in brackets thus :—(19) refer to Bibliography Section.

Directional Transmission. In looking back through the early history of the study of Electro-Magnetic Wave phenomena, it is found that attempts were made to obtain directional transmission long before the subject had any practical application for the purpose of telegraphic communication. The primitive transmitting apparatus used in these early investigations was capable of radiating only comparatively low power, and since the receiving devices were also of an insensitive nature, it appeared essential to adopt some means of concentrating the radiated power in the form of a beam directed towards the receiver. By this means it was hoped to avoid the losses which result from transmitting broadcast in all directions with equal intensity, but the problem was a difficult one, and even at the present day a complete solution has not been found, although great progress has been made.

In an historical note in this introductory chapter, some of the outstanding experiments on directional transmission and reception during the last quarter of a century have been briefly mentioned, and during this period wireless telegraphy has passed through the various stages from a laboratory experiment in practical physics to an almost universal and international method of communication of ever increasing importance.

Directive Transmission and Reception. As the means of radiating greater amounts of power were developed and receivers were made more sensitive, it was found that communication could be carried out over distances up to many hundreds of miles with aerial systems which were only slightly directional in their properties, and so the urgency for beam transmission, for economic reasons and in order to obtain the desired range, became less apparent ; indeed, of later years there has been very little attempt to achieve directional transmission of high powers.

It has been realised for a long time that if wireless transmitters or receivers could be given accurate *directive* properties as, for example, a definite maximum radiating or receiving

property in one direction and definite minimum (or zero) radiating or receiving properties in another direction, the scope of wireless communication could be extended and the position of a transmitting station could be found by purely wireless means.

It is these precise directive properties as applied to position finding and navigation rather than the merely directional properties of a transmitter for economic reasons, which are dealt with in the ensuing chapters, and more particularly, the directive receiving station.

Comparison of Visual and Wireless Means of Direction and Position Finding. The operation of direction finding and navigation by wireless is closely allied to the visual means, and a comparison of the two methods indicates clearly the value of the former, but also its limitations. Suppose that the noise from a passing aeroplane attracts our attention, and we notice that a machine of such and such a registered number is flying 500 feet high and that it is, at the moment, about a quarter of a mile north of us. All this information can be obtained from a comparatively rapid glance, and this is rendered possible owing to our eye-brain combination which interprets the effect of light reflected from the aeroplane and surrounding country, in the form of the information mentioned above.

Limitations of the Visual Method. Had the aeroplane been several miles distant, our attention would not have been attracted in the first place because we should not have heard the noise. Again, if the machine had been obscured by darkness or fog, all visual means of gaining information are ruled out. Wireless telegraphy has enabled communication to be carried out between aircraft, ships or shore stations when the distances are enormously greater than could possibly be spanned by any visual means, but it was in order that we might *see* by wireless means, over these great distances, as well as *hear* which has stimulated the development of the wireless direction finder.

Propagation of Light and Wireless Waves. Both Light and Transmitted Wireless Energy are forms of vibration or wave motion in a medium known as the "ether," which pervades the whole of space. Both are normally propagated in straight lines with a velocity of 300 million metres per second (or approximately 186,000 miles per second). Light is made manifest to us because the speed of vibration of the

ether corresponding to light of various colours is able to affect the eye-brain combination whilst, on the other hand, we have no sense capable of perceiving, even to the smallest degree, the existence of the relatively much slower vibrations in the ether which correspond to the transmission of what we term "wireless energy."

The way in which these waves are actually detected is by their conversion into some other form of energy such as sound, which can be perceived by a sense which we already possess, and it will be assumed that the reader already has some knowledge of how this conversion is achieved, although a *résumé* of portions of the subject will be found in Chapters 2 and 3..

DIRECTION FINDING BY WIRELESS MEANS.

Directive Reception. The Direction Finder (D.F.) is a type of wireless receiving station which, in virtue of the properties of a certain type of aerial system, makes it possible to find the horizontal angle of incidence of received signals relative to some standard, which is almost universally taken as the direction of true North. The process of taking the bearing of the distant station consists in rotating the directive aerial system until a certain alteration in the intensity of the signals indicates to us that the plane of the aerial system and the direction of incidence of the wireless signals bear some definite prearranged relation. The rotating portion of the system is calibrated from 0° to 360° set out in a clockwise direction, that is to say, from North, through East, South and West, so that the resulting angle will be measured off as a bearing in degrees East of North. This operation can be carried out no matter what distance the source of the signals is from the receiving station, so long as the signal intensity is great enough for aural reception.

Position Finding by Directive Reception. Just as distances judged by the naked eye are liable to serious errors owing to optical illusions, etc., so the distance of a wireless transmitting station judged by the strength of received signals is also only very roughly correct, although in both cases experience will bring a measure of accuracy.

In practical position finding, therefore, the method of "Course and Distance" is never employed, and it is usual to erect two or more D.F. stations and employ the triangulation methods of ordinary surveying. Thus in Fig. 1 if A

and B are two D.F. stations and C is an aeroplane having a wireless installation, then if the directions of the incident waves at each of the D.F. stations be found relative to the direction of North, and if these directions are laid off on a

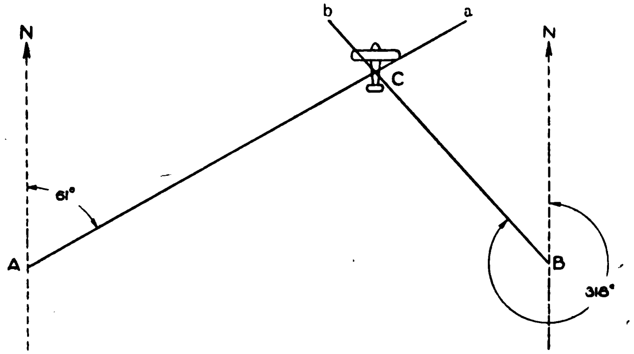


Fig. 1. *Position Finding by Directive Reception at two Stations A and B.*

map A*a* and B*b*, then the position of the aeroplane must be at the intersection of the two lines. In Chapters 4 and 5 the subject is dealt with from a practical standpoint, and there is also introduced the important modification of the above methods when the directive receiver is located on the aeroplane or ship, as the case may be, enabling the observer on the mobile station to note the bearings of fixed transmitting stations and use them for navigational purposes.

HISTORICAL NOTES.

Although some of the methods adopted in the early days for directional transmission have no application in the modern direction finder, a short historical record is of interest, as it shows the development of the present-day apparatus.

Mirror Reflectors. Hertz, in his extremely important original researches, demonstrated the fact that both light and electro-magnetic radiation were similar forms of energy by showing that they could both be reflected in the form of a beam by means of mirrors (1). For the purpose of concentrating the transmitted electro-magnetic wave motion, he made use of cylindrical parabolic mirrors about two metres high and one metre in width and obtained successful results, using a wavelength of about two-thirds of a metre.

In later years when Marconi attacked the great problem of practical wireless communication, he also made successful use of copper parabolic mirrors and was enabled to detect, at a distance of two miles, the beam transmitted in this manner (2), (142).

Screening. Experiments were carried out in Germany by Zenneck in 1900 in connection with the screening of a vertical aerial in certain directions, by the erection of additional vertical wires (3). From his own accounts of his work, it would appear that Zenneck was on the verge of important discoveries regarding the properties of spaced aerials, but the work seems to have been discontinued after moderately promising results had been obtained.

In other countries work was being carried out along similar lines and led to the complete wire screen or reflector which superseded the mirror for this purpose.

Screen Reflectors. The use of mirrors became totally impracticable when use was made of a wavelength of a number of metres, as it is necessary that the size of the mirror should at least be comparable with the dimensions of the wavelength employed. (An optical mirror, for instance, of one centimetre in diameter is more than a hundred million times the dimensions of the greatest wavelength it is required to reflect). A number of inventors realised, however, that a satisfactory reflector could be formed of vertical wires, spaced about the transmitting aerial in the form of a parabolic screen and arranged so that the transmitting aerial was at the focus, or along the focal line of the cylindrical mirror so formed. Patents were granted to S. G. Brown in 1899 (*a*) and to Lee de Forest (*b*) in 1902 for inventions of this nature. Modifications of this type of reflector are in use at the present day, but the wavelengths used are extremely small by comparison with those normally used for commercial work (see page 11).

Horizontal, Inclined and Bent Aerials. From 1900 onwards, the attention of a number of experimenters has been turned to the use of aerials having a horizontal portion, and accounts were published by Galliot (4), Kiebitz (5), Marconi (6), and a patent was applied for by de Forest in 1901 (*c*) for a radiator having both vertical and horizontal limbs.

F. Braun in 1902 obtained a degree of directional effect with a straight inclined aerial (7), (8), (9), and the use of

(*a*) British Patent 14449/99. (*b*) U.S.A. Patent 748597/02.
(*c*) U.S.A. Patent 749131/04 (being a divided part of an original No. 720568/01).

horizontal aerials close to the ground, for the same purpose, has been proposed by other workers, including Marconi (*d*), Zehnder (10) and Kiebitz (11), and these "grounded aerials" still have a limited field of use.

Of the above methods of obtaining directional transmission or reception, the one which had the greatest promise of wide commercial application, by the employment of a bent aerial, was the Marconi inverted L aerial, which is shown diagrammatically in Fig. 2. If the horizontal limb of such an aerial be

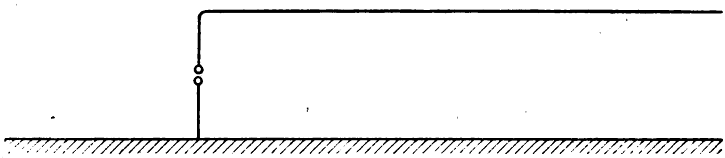


Fig. 2. The Marconi "Inverted L" Aerial.

made considerably longer than the vertical portion, the radiating (or receiving) property is found to be greater in a direction opposite to that in which the horizontal limb is pointing (12), (13). In 1905, Marconi patented (*e*) the combination of an inverted L transmitting aerial with a similar receiving aerial, claiming that very appreciable directional effects could be obtained in this manner. A further patent was taken out in 1906 (*f*) for a method of direction finding in which a number of inverted L aerials were erected with the horizontal portions equally spaced in a radial manner about the receiving apparatus. On connecting the aerials in turn to the receiver, the one which gave the greatest signal intensity was assumed to be pointing away from the distant station, and hence the direction of the incident waves could be found approximately.

This type of aerial is still in common use, but in the case of the inverted L transmitting aerial, the directional properties have been somewhat eclipsed by the value of this particular form of construction as a means of obtaining an aerial of large capacity—a very necessary feature of a high power installation.

Spaced Aerials. The augury of accurate wireless direction and position finding may be said to date from the early investigations of the radiation of a system of two (or more) aerials, the currents in which bore definite phase and amplitude relations one with another. In such a case the received energy at any distant station is that due to the combined

(*d*) British Patent 12039/96. (*e*) British Patent 14788/05.
(*f*) British Patent 3127/06.

effect of both (or all) the transmitting aerials, and whilst in some directions these may assist one another and give a maximum of received energy, there may be other directions from which the effects neutralise one another and the reception is zero.

In Chapter 2 we shall investigate the way in which two spaced open aerials or a single closed loop aerial are affected by an incident wave and how such aerial systems come to have directive properties, but for the purpose of this brief historical survey it is enough to note that these properties exist, and, moreover, that they have a very important bearing on modern methods of direction finding.

The polar diagrams of radiation or reception (page 18) for a large number of conditions of spacing of aerials and phase differences of the respective aerial currents, are described by Zenneck (3), Bellini (15), L. H. Walter (16), and a number of other writers.

As early as 1899, S. G. Brown claimed directive properties for a system of two vertical aerials, connected to the spark balls of an induction coil and spaced half a wavelength apart (*a*). Such an arrangement was shown to have maximum radiating and receiving properties in the plane of the two aerials. Patents were also granted to M. R. Garcia (*g*) and to Lee de Forest (c) for inventions of a similar nature, and in 1903, A. Blondel suggested another arrangement of two spaced aerials to obtain the same directive results as S. G. Brown.

In 1902, the directive aerial system of S. G. Brown was adapted by J. Stone Stone (*h*) for use as an actual direction finder, but since he proposed to rotate the two aerials, spaced half a wavelength apart, about a vertical axis midway between them, the suggestion was scarcely a practical one. These difficulties prevented S. G. Brown or J. Stone Stone from realising a practical direction finder, but their achievements may be said to have laid the foundation of the more modern systems.

In 1906, Prof. F. Braun (9) described a method of obtaining a "heart-shaped polar diagram of radiation" (page 38) by means of three vertical aerials situated at the corners of an equilateral triangle and in which currents, bearing definite phase relations with one another, were produced by a method devised by N. Papalexi and L. Mandelstam (18).

(*g*) U.S.A. Patent 795762/01. (*h*) U.S.A. Patent 716134, 716135/02.

A scheme for avoiding the necessity of rotating the spaced aerials of S. G. Brown and others was introduced in 1907 by E. Bellini and A. Tosi (*j*), and the modern Bellini-Tosi system is described in detail in Chapter 2, the modern aerial system being illustrated in Fig. 165. As originally devised, the aerials were open ones, although it was common practice to have them inclined so that the four upper ends of the aerials should be supported from a single central mast. In 1912, C. E. Prince (*k*) modified the Bellini-Tosi aerial system by converting the four open aerials to two closed loops, and the progress in the further development of the system forms the subject of the latter part of Chapter 2.

Small Rotating Loop Aerials. One of the famous experiments of Hertz was to show that when a loop of wire containing a spark gap was held in certain positions in the neighbourhood of apparatus which was radiating electromagnetic waves, a spark would pass between the spark balls; if, on the other hand, the orientation of the loop were slightly changed, but the loop kept at the same mean distance from the radiation, the spark would no longer be produced. He ascribed this to a property of the loop as an absorber, a characteristic which had probably been noticed even before this date by Fitzgerald (19).

H. J. Round gives an account (19) of experiments which he carried out in New York in 1905 and 1906 which demonstrated the directive properties of frame aerials, and he also obtained a heart-shaped diagram of reception of approximately the form shown in Fig. 24 by the combination of frame and open aerials, but largely owing to the insensitiveness of his detector, the work was abandoned.

LATER PROGRESS.

It was the advent of the European war, giving, as it did, such a great stimulus to all wireless progress, which also raised the direction finder from a comparatively undeveloped state and resulted in the production, within a year or two, of a reliable instrument. The valve amplifier was largely responsible for this advance in direction finding work, as the increase of range of the apparatus and the increase in signal intensity brought to light faults which had been overlooked in the earlier designs. With the amplifier, there came

(*j*) British Patent 21299/07. (*k*) British Patent 2456/12.

also a very great increase in the popularity of the small frame aerial, since, by the use of cascade amplification, the signal intensity could now be magnified thousands of times. The French Army and the United States Navy adopted the rotating frame as their method of D.F., and still retain it.

In Great Britain the simple rotating frame aerial as a D.F. has never had any extensive use, though the Royal Air Force adopted a system due to Capt. J. Robinson, in which a combination of two rotating frames is employed, and this is described on pages 45 and 302. The British Expeditionary Force, during the European war, and also the British Navy, made considerable use of the Bellini-Tosi system (19), and the methods described in the next chapter for overcoming many of the inherent defects of the loop aerial as a D.F. were developed in connection with this system.

THE RADIOPHARE, OR DIRECTIVE WIRELESS TRANSMITTER.

Another method whereby the observer at a mobile wireless station may find his bearing from a fixed transmitting station is in the case when the latter is equipped with a directive transmitter.

The accuracy obtainable with these Radiophare stations is not so great as when directive receiving stations are used, and their chief advantage is that they enable any number of ships or aircraft to find their bearings without the necessity for wireless communication—an important feature in wartime.

The Bellini-Tosi Radiophare. Although the B-T system has been referred to up to the present only with regard to reception, the directive properties of the system are equally applicable in the case of transmitted energy and the apparatus used is also readily adaptable. The general principle of the Radiophare is that the direction of maximum radiation from the station is arranged to be continuously rotated in a clockwise direction at constant speed. At given intervals, corresponding to a known bearing, a distinctive signal is transmitted, and thus any ship or mobile station equipped with receiving apparatus is enabled to find its bearing from the transmitter by noting the signal corresponding to maximum signal intensity. (It will be explained later that it is usual to note the minimum signal strength, but this does not affect the principle involved.)

The Telefunken Compass. This system makes use of a series of directional aerials radiating from a single mast, which also supports a non-directional type of aerial as shown

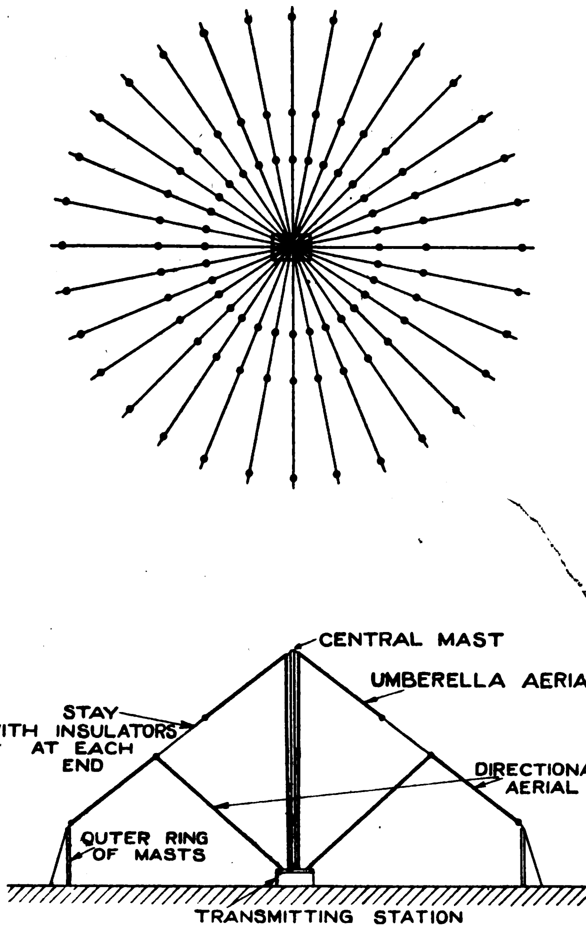


Fig. 3. *The Telefunken Compass.*

in Fig. 3. The method of operating the station is as follows. At pre-arranged intervals a time signal is transmitted on the non-directional aerial and is immediately followed by a series of further signals, sent at intervals of one second on each of the directional aerials in turn. There are thirty-two of these aerials (corresponding to the points of the magnetic

compass) and the direction of transmission will therefore rotate through a complete circle in thirty-two seconds, and is arranged to start and finish with the direction of North. All ship stations who wish to make use of the scheme are supplied with a special stop-watch, which has its dial marked out in the form of a compass and the finger of which rotates once in thirty-two seconds. If, then, on hearing the time signal, the telegraphist starts his stop-watch and listens until the transmitted signals reach their maximum strength and then stops his watch, the pointer will indicate the direction of the transmission at the instant and hence the bearing of the ship from the transmitting station (112).

The Beam Radiophare. The use of Screen Reflectors, referred to on page 5, has been developed by the Marconi Company in considerable detail during recent years, resulting in a rotating beam Radiophare in which the width of the beam is sufficiently small to allow of the instant of maximum signal strength being employed at the receiving station, for the determination of a bearing with comparative accuracy. Since the size of the reflector must be, at least, of the same order as the length of the transmitted wave, it is necessary to utilise extremely short waves and in practice, wavelengths of from 1 to 15 metres are employed in the apparatus mentioned above. A special receiver is required for these short waves but against this fact is the advantage of immunity from interference from atmospherics or from other transmitting stations (130) (142).

The R.A.F. Directive Transmitter. The D.F. system of Captain J. Robinson has been adapted by the Royal Air Force to directive transmission, whilst still retaining the same distinctive features which are described on page 45 in connection with the directive receiver (125).

CHAPTER 2.

THE THEORY OF THE WIRELESS DIRECTION FINDER.

Mental Picture of Wave Propagation. We do not propose to enter at any length into the theory of propagation of electro-magnetic waves; for a mathematical discussion of this portion of the subject, reference must be made to other treatises on wireless telegraphy.

It is essential, however, that the reader should have some mental picture of an ether wave in order that he may understand the explanation of frame reception, etc., which follows.

Waves are propagated in straight lines; that is, a wireless signal travelling from one point—the transmitting station—to another—the receiving station—does so by the shortest possible route. On the earth, this is not a straight line in the ordinary sense of the word owing to the spherical shape of the globe, but the wave still travels by the shortest path, which is known as a "Great Circle." The exact nature of this curved route will be discussed more fully in Chapters 4 and 5.

Suppose a wave to be travelling between two points on a plane surface, that is, between a transmitting and receiving station. The wave consists of a system of electric and magnetic lines of force at right angles to each other, and if we imagine an observer standing in the path of the wave facing the transmitting station, and if he extends his arms, they will lie along the direction of the magnetic force at any instant. That is to say, the magnetic force is parallel to the ground but is at right angles to the direction of travel of the waves. The electric force is also at right angles to the path of the wave but is perpendicular to the ground, so that the body of the imaginary observer would indicate the direction of this component of the wave.

In any normal wave travelling over the surface of the earth the directions of the electric and magnetic components always bear the foregoing relationships to each other. No wireless wave can travel far over the surface of the earth unless it has "its feet on the ground" or, in other words, the lines of electric force vertical, the lower ends sliding over

the surface of the earth, and the magnetic lines horizontal and parallel to the earth's surface. It will be noted that the wave as a whole moves broadside on.

So far, we have only noted the *directions* of the electric and magnetic components of the wave. In an actual wave, these forces, although constant in direction, vary in *intensity*. If our observer were equipped with some suitable means of determining the intensity of the magnetic force as the wave passed, he would see it starting from zero and gradually growing to a maximum, then dying away to zero again and reversing its direction, after which it would grow to a maximum again in the opposite direction and again fall away to zero. This cycle of events would be repeated over and over again as long as the wave lasted, the electric force following an exactly similar cycle in step with the magnetic component.

The forces actually vary in accordance with a sine law, and consequently the wave can most conveniently be represented graphically by a sine curve whose ordinates are proportional to the intensity of the forces at different points in the wave and with a "time" base. The whole system of forces must be considered as moving forward with the velocity of light.

It should be observed that electro-magnetic waves can exist in the regions above the earth in which the electric and magnetic components are not strictly perpendicular and parallel to the surface of the ground, but at the same time, no matter what degree of twist or "polarisation" (see page 165) the wave may have, the two forces are always at right angles to each other and the direction of propagation is always perpendicular to both.

Wavelength. The wavelength of an electro-magnetic wave is defined as the distance between two points where the forces are a maximum *in the same direction*, so that in Fig. 4

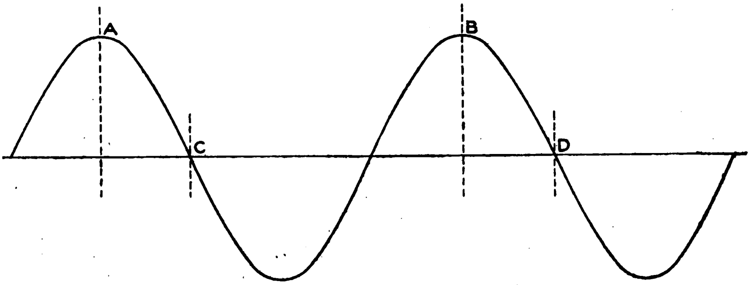


Fig. 4. Measurement of Wavelength.

the wavelength would be measured by the distance **AB.** From the symmetry of the wave it will be noticed that this is the same as the distance CD, so that we can define the wavelength of any wave as being the distance between any two points where the forces are of identical intensity *and are changing in the same manner.* In practice, wavelengths vary from a few metres to about 30,000 metres.

Frequency. It was mentioned above that the speed of travel of the electro-magnetic wave is equal to that of light, namely 300 million metres per second. Now, the frequency with which the successive wave crests pass a fixed point in the path of the wave must equal the total distance travelled by the wave in a second divided by the distance between the successive wave crests, or,

$$\text{Frequency} = \frac{\text{Velocity}}{\text{Wavelength}}$$

and thus we see that a wavelength of, say, 3,000 metres corresponds to a frequency of

$$\frac{300{,}000{,}000}{3{,}000} = 100{,}000 \text{ per second.}$$

Continuous, Interrupted Continuous and Damped Waves. If the type of transmission is that known as continuous waves, then, as the name implies, during the passage of the wave, the intensity of the electric and magnetic forces will vary sinusoidally with a constant amplitude and at a frequency depending, as we have just seen, upon the length of the waves. This may be represented as in Fig. 5(a). In the interrupted continuous wave motion (I.C.W.), the wave train is broken up into a number of short trains of oscillations, each lasting for a period which may vary from, say, 1-500th to 1-2,000th of a second, and with a similar short period of inaction between each train. Fig. 5(b) shows this type of transmission.

A further type is the Damped or "Spark" wave, and here the continuity of the wave train is again broken up, but each short train of oscillations steadily falls off in amplitude, and usually is reduced to zero so rapidly as to leave a greater blank period than in the case of the I.C.W. The total number of complete oscillations which take place before the wave train is reduced to zero (or a negligibly small amount) is a function of the damping of the transmitting circuits, and will not be dealt with in detail here as a certain amount of

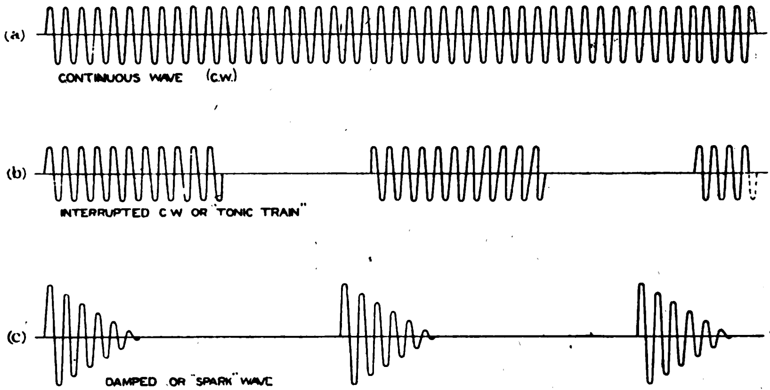


Fig. 5. Types of Wave Trains.

familiarity with this part of the subject is assumed on the part of the reader. Fig. 5(c) shows diagrammatically the damped wave trains.

How a Simple Vertical Aerial Receives. In considering the manner in which an aerial receives, it is convenient for the sake of clearness to think of the magnetic force in the wave only. In this case our sine curve will represent the intensity of the magnetic field at any point in the wave.

When a conductor is cut by lines of magnetic force an E.M.F. is produced in it; this is one of the elementary principles of electro-magnetism. The intensity of the electromotive force generated in the wire is proportional to the *rate* at which the lines of force cut it. If 100,000,000 lines cut the conductor in a second, the E.M.F. produced is 1 volt, and consequently, if 1,000,000,000 lines cut it in one second, the E.M.F. produced is 10 volts, and so on.

Now we have explained that an ether wave consists of a set of lines of electric and magnetic force moving broadside on its direction of propagation. Since the magnetic force is horizontal, it follows that any conductor placed vertically in the path of the wave will be cut by these lines of magnetic force and consequently will have an E.M.F. induced in it. The E.M.F. will vary as the magnetic flux varies, and will be proportional to the rate at which the flux cuts it. In practical wireless telegraphy this conductor is known as the aerial wire, and the state of affairs in the case of a receiving station is shown in Fig. 6. In this figure the aerial wire is

represented by AB, the incident wave being indicated by the sine curve, the ordinates of which are a measure of the intensity of the magnetic flux in the wave at various instants. In Fig. 6 (a) we have an instantaneous picture of the relative positions at a point where the sine curve is crossing the zero axis and where there is consequently no magnetic flux. At this point

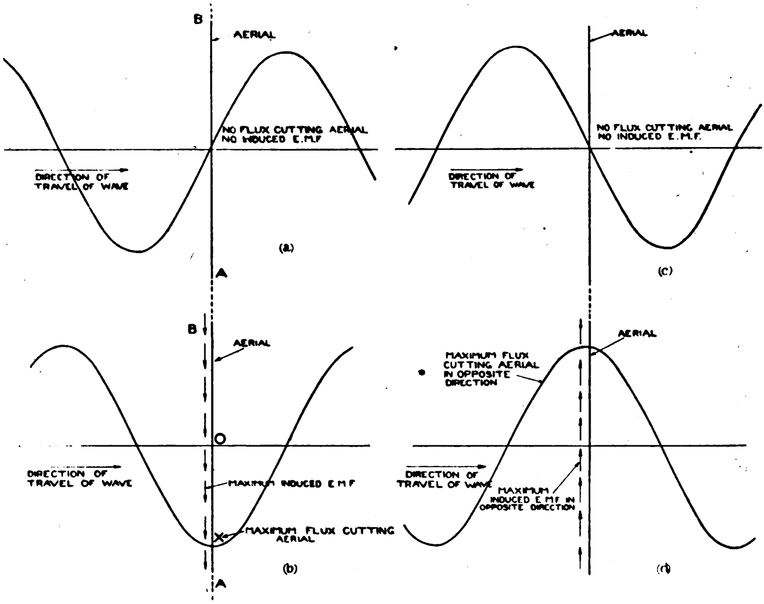


Fig. 6. *Induction of Alternating E.M.F. in an Open Aerial by an Electro-magnetic Wave.*

there is no E.M.F. induced in the wire AB because there are no lines cutting it. Fig. 6 (b) shows the state of affairs a moment later, when the wave has moved forward a quarter of a wave-length, the intensity of the field cutting the aerial being represented by the line OX. This field is at its maximum value in the negative direction and therefore the maximum negative E.M.F. is being generated in the wire. A quarter of a wave-length later, the flux is again zero, accompanied by zero E.M.F. in the wire as shown in Fig. 6 (c). The flux now reverses in direction and commences to grow to its peak value in the positive sense, the E.M.F. in the wire following exactly until, in Fig. 6 (d), it has again reached a maximum, but in the opposite direction to that shown in Fig. 6 (b).

From these considerations it is clear that the E.M.F. induced in the wire in sinusoidal, because the intensity of the flux is represented by a sine curve. We thus see that an alternating E.M.F. is induced in the aerial wire of the same frequency as that of the wave passing it, and it is important to notice that the E.M.F. induced is *in phase* with the flux in the wave, being a maximum when the flux is a maximum and zero when the flux is zero.

Aerial Tuning. Now a vertical wire, grounded at its lower end, can be considered as an ordinary alternating current circuit containing Inductance, Capacity and Resistance. The inductance is that of the wire itself, the condenser is formed by the capacity of the wire to earth, and the wire will always have a certain resistance.

We have seen that when a wave passes this wire, an alternating E.M.F. is induced in it, as a result of which a current will flow. The magnitude of the current will depend on the impedance of the circuit, just as it does in the case of an ordinary low frequency alternating current circuit. The impedance of any circuit is dependent upon the relation between the inductance and capacity in it, and is a minimum when the inductive and capacity reactances are equal in value. When this latter condition exists, the maximum alternating current will flow in the circuit for any given applied alternating E.M.F.

The operation of " tuning " an aerial consists in adjusting its effective inductance and capacity by means of coils and condensers until the circuit has the least possible impedance—at the frequency of the incoming signal—in order that we may obtain the maximum current as a result of the E.M.F. induced by the signal.

When an aerial is " in tune " with the incoming signal the state of affairs is such that the total inductive and capacity reactances of the aerial circuit are equal, and this will include not only the self capacity and self inductance of the aerial wire, but also any tuning inductances and series or parallel tuning condensers. Under these conditions, the current which flows in the circuit is dependent solely upon the resistance of the wires, consequently, in order to make an aerial system as efficient as possible, we should cut down all resistances to a minimum.

We have stated above that the E.M.F. induced in a conductor is proportional to the number of lines cutting it, and

this fact at once explains why increasing the height of an aerial wire also increases the strength of signals received. Since the field is horizontal, it follows that if we make the wire longer in a vertical direction, then a larger number of lines will be cutting it at any instant, and hence the amplitude of the induced alternating E.M.F. will be greater and also the signal strength.

Polar Co-ordinates. It is thought advisable at this juncture to introduce a method of representing pictorially the receiving or radiating power of an aerial in different directions.

It is perhaps simpler in the first instance to illustrate the method by reference to the case of the transmitter. In Fig. 7 let us suppose that the point O represents a transmitting aerial sending out waves in all directions. Now it is quite possible that the power radiated may vary according to the direction in which the wave leaves the aerial. A very convenient way of settling this point would be to take a portable receiving set and to walk round the transmitter, keeping the receiver at a constant distance from the transmitting aerial, and measure the strength of received signals at equi-distant angles all the way round. Then if we draw in the diagram a series of radial lines from the transmitting aerial, each line passing through one of the points where the strength of signals was measured, and if we make the *lengths* of these lines correspond to the *intensity* of the received signal, the curve obtained by joining the extremities of these lines will indicate the way in which the aerial is radiating.

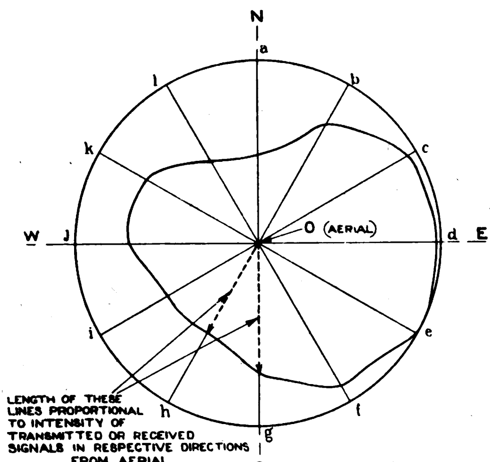


Fig. 7. Diagram to illustrate the use of Polar Co-Ordinates.

In Fig. 7 we have supposed that the signal strength was measured at the points a, b, c, d, e, f, g, h, i, j, k, l, and

in each case a length has been marked off along the corresponding radius to represent the intensity of the signal, the points so obtained being joined up to form a continuous curve. It will be seen that, assuming North to be at the top of the page, the strongest radiation was observed just a little South of East, and that weak directions were West of South and West of North. In this manner we obtain a picture which at once creates a mental image of the variations of radiation round the aerial.

Exactly the same graphical method can be adopted to represent the receiving power of an aerial, and the strength of signals received on any aerial may vary according to the direction from which the waves are arriving, just as in the case of the transmitter, although the circumstances are reversed.

Referring to Fig. 7 again, O might represent the centre of some receiving system, and a, b, c, etc., will then indicate various angles of incidence of electro-magnetic waves and the strengths of received signals are then marked off on the respective radii and the points joined up to form a smooth curve. This curve will then indicate the receiving power of the aerial from different directions. We may note at this point that "radiating power" and "receiving power" are in almost all cases interchangeable; that is, if any aerial radiates best in any particular direction, it will also receive best in that direction. The fact is of importance as it enables the directional *receiving* properties of an aerial to be studied by the method mentioned above for a transmitting aerial, thus avoiding the necessity of erecting and dismantling a transmitting station a large number of times.

Polar Diagram of a Vertical Aerial. From what has already been said on page 15 concerning the way in which an E.M.F. is induced in an open aerial by an electro-magnetic wave, it will be clear that if the aerial be perfectly vertical and the earth equally conducting in all directions, then the E.M.F. induced in the wire will be the same for equal intensities of the wave, no matter what the direction of incidence of the wave may be. The polar curve of such an aerial will, then, consist of a curve drawn through the extremities of a series of equal radii from the point representing the aerial, and will be a circle.

Equation of Circle Diagram. The circle diagram for the vertical aerial is shown in Fig. 8. It is sometimes convenient

to express the polar curve of reception of an aerial in the form of an equation of the form :—

$$r = \text{function of } \theta$$

where r is the length of the radius of the curve for a given angular displacement θ relative to some arbitrary starting direction. In the present case, since r is always the same, no matter what the angle may be, the equation resolves itself simply into the expression: $r = C$, where C is a constant.

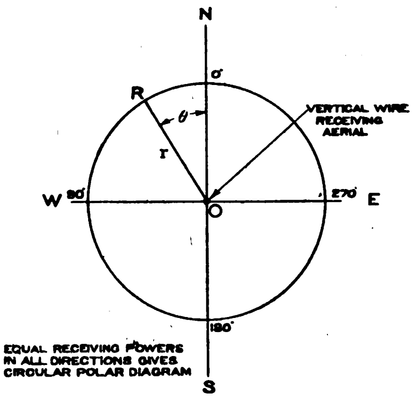


Fig. 8. Polar Diagram of Open Aerial.

The value of the above method of expressing polar curves will become more apparent when we deal with the frame aerial and the combination of frame and vertical aerials.

How a Frame Aerial Receives. A frame aerial consists of a closed loop of wire, generally either square or triangular in shape, and may comprise one or more turns. The aerial is erected with its plane vertical and is tuned by means of a variable condenser placed in the base member of the loop, on either side of which inductances may be inserted for tuning and coupling purposes. Such an aerial circuit is illustrated diagrammatically in Fig. 9. In this figure, *a*, *b*, *c*, *d* represents the aerial conductor, C_1 is the variable tuning condenser and L_1 L_2 are the inductances in series with the loop. Two inductances have been shown, and it should be noted that when an inductance is inserted in a frame aerial it is usually split up into equal parts on either side of the condenser for the sake of symmetry, which we shall find later to be an important factor.

Such an aerial is really an enlarged closed oscillatory circuit, and it is exactly similar to the ordinary wave-meter except that the " coil " is of very much greater dimensions. The loop possesses certain inductance and has in series with it the inductances L_1 and L_2, and consequently the circuit as a whole can be tuned to various wavelengths by altering the capacity of the condenser C_1

Imagine such a loop to be supported above the ground in Fig. 9, and let an electro-magnetic wave be arriving from the right-hand edge of the page, that is in the direction of the arrow. For the sake of clearness we will only consider the effect on the loop aerial of the magnetic component of the field.

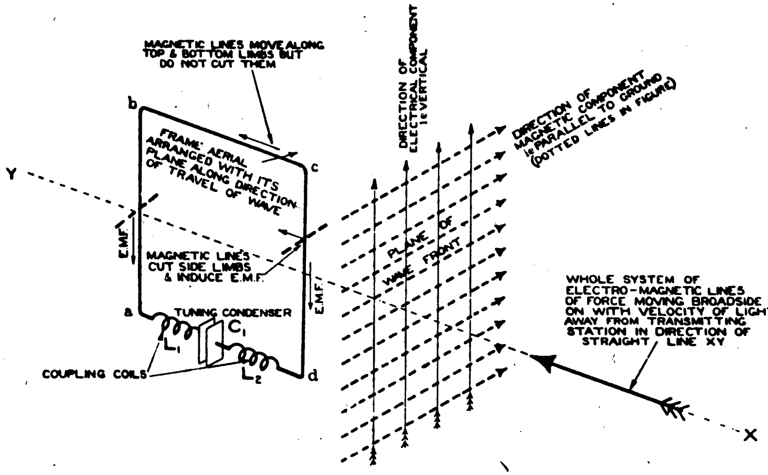


Fig. 9. *Frame Aerial in position of Maximum Linkage with Magnetic Flux in a Wave.*

Supposing the whole system of lines to be moving past the loop in the direction of the arrow X, it will be seen that neither the leg *b c*, nor the leg *a d* is cut by these lines because they lie along the direction of travel of the wave. The sides *a b* and *d c*, on the other hand, are cut by the field and will have E.M.F.s induced in them, the magnitudes and directions of which will be governed by the intensity and direction of the portion of the field cutting them at any instant.

Now, the only E.M.F. which can be effective in producing a current *round* the loop is one which acts *round* the circuit, and consequently if the E.M.F.s at any instant are of equal strength but of opposite direction *round* the loop, no resultant E.M.F. will exist and no current will flow. In general, it may be said that the effective E.M.F. acting round the loop at any instant is the algebraic sum of the E.M.F.s in the two vertical legs, by which is meant that when the E.M.F.s are acting in opposite directions round the loop, the resultant will be given by the difference of the two, and when they act together, the resultant is equal to their sum.

In Fig. 10 we have illustrated this point graphically. Let the length *a d* represent the base *a d* of the frame shown in the previous figure, drawn in proportion to the wavelength of the sine curve representing the incident wave. It has already been seen that the ordinates *a* X and *d* Y will measure, respectively, the E.M.F.s induced in *ab* and *ac* at the particular instant under consideration. These E.M.F.s are both in the positive direction round the frame *abcd*, so that the resultant E.M.F. will be given by the difference of *d* Y and *a* X and will have a value proportional to the intercept YZ on *d* Y.

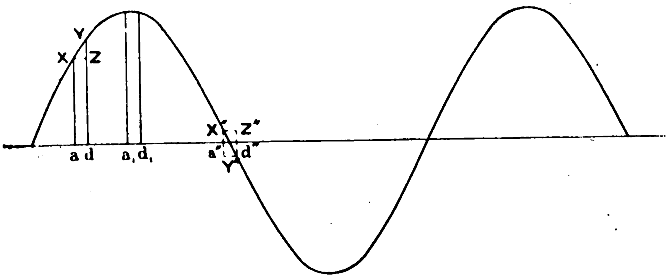


Fig. 10. *Phase of Induced E.M.F. in Frame Aerial.*

At another instant when the wave is just at its maximum and the frame is in the position *a′ d′*, the ordinates are equal and therefore no resultant E.M.F. exists. In the position *a″ d″*, when the wave is just crossing the zero line, since the E.M.F. *a″* X″ is in the positive direction and *d″* Y″ is in the negative direction, both E.M.F.s are acting in the same direction round the frame and the effective E.M.F. is represented by the length Y″ Z″.

A study of this diagram will make it clear that the maximum E.M.F. is acting round the frame when in the position a″ d″ and that the total resultant E.M.F. is an alternating one *which has its maximum value when the flux in the wave passing the frame aerial is zero and has its minimum value when the flux is at its maximum.*

This result should be compared with that arrived at on pages 15 to 17 in considering reception by a vertical aerial, in which case we found that the E.M.F. was *in phase* with the flux in the wave.

The Polar Diagram of a Frame Aerial or "Figure 8" diagram. In the above explanation we have assumed the incoming wave to produce an E.M.F. in each vertical leg of

the loop, the active E.M.F. round the loop being the resultant of the two. This method of looking at the matter was chosen on account of the fact that it at once makes clear the phase difference between the wave and the E.M.F. it produces.

In considering the polar curve of such an aerial it is much simpler to regard the effective E.M.F. as being proportional to the *total linkage of the magnetic flux* in the wave with the loop. There is no essential difference in the two ways of considering the problem and it is preferable to choose the simpler.

Now the E.M.F. which is induced by a magnetic flux varying according to the sine law, in a loop of wire threaded by it, is proportional to the effective number of lines so linked with it. In the case of our frame aerial it can be seen that the maximum number of lines are linked with the loop when it is directly pointing towards the transmitting station (keeping in mind the picture of the wave travelling with magnetic field horizontal and at right angles to the direction of travel). When the frame is turned so that it is exactly broadside on to the sending station, there will be no magnetic flux linked with it, because the plane of the loop will lie right along the lines of force, hence there will be no E.M.F. induced round the loop, and consequently no signals will be received. We can thus see that this type of aerial possesses very marked directive properties, inasmuch as it receives best when it is pointing towards the transmitter and receives nothing at all when turned at right angles. The condition existing at intermediate positions can best be studied by means of a diagram.

In Fig. 11 we have shown a frame aerial in plan, in various positions in a uniform magnetic field, the vertical conductors being represented by the dots A, C, E, G, I, etc. and the successive positions of the frame by the lines AB, CD, ED, etc. The magnetic field is represented by the lines which cover the figure, and since we are presupposing the field to be uniform, these lines are spaced at equal distances apart. If, now, we count the number of lines enclosed between the vertical conductors of the frame in any position, the number will represent the E.M.F. induced by the passing wave as explained above. Then, by plotting out the numbers so obtained in the form of a polar diagram, we shall obtain an idea of how the receiving power of the frame varies in different positions.

Taking first the case when the frame is in the position AB; since it is lying parallel to the lines of force, there is no linkage with it and consequently no E.M.F. induced. In the position CD, however, there are lines passing through the frame, and

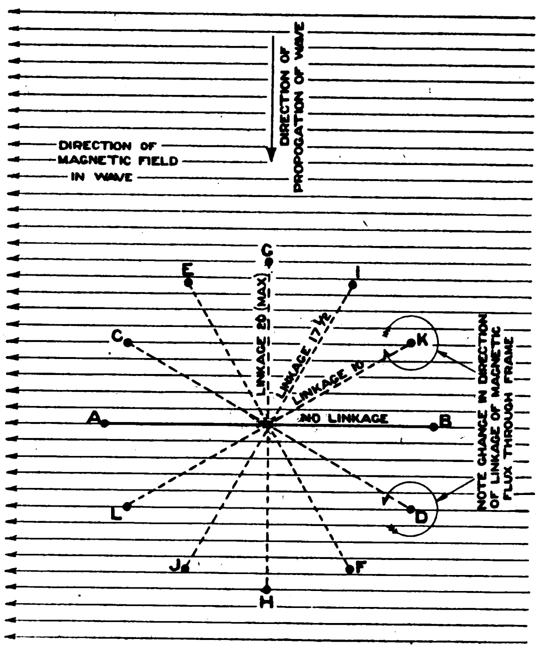


Fig. **11.** *Variation of Linkage with Rotation of Frame.*

if the number between the dot C and the dot D are counted, it will be found that ten are so linked. (It will be preferable to count spaces instead of lines in order that fractions of a space may be considered which would otherwise lead to confusion if we were dealing with lines.) There are $17\frac{1}{2}$ between E and F, and 20 between G and H, and then the number of linkages begins to grow smaller again, there being $17\frac{1}{2}$ between I and J, 10 between K and L, and none when the frame is in the position BA. The growth in E.M.F. now recommences until it is a maximum between H and G, and then falls to zero again at AB.

It is important to notice that although the same number of lines are linked at KL and DC, the lines pass through the frame in opposite directions, and therefore the E.M.F.s

induced will be in opposite directions round the frame. This change occurs at BA and we thus see that when an alternating E.M.F. is being induced in a frame aerial by an incident wave, *the phase of the E.M.F. will be shifted through* 180° *as the frame is rotated through the position of zero linkage.*

Tabulating these results, we have :—

Position of Frame.	AB	CD	EF	GH	IJ	KL	BA	DC	FE	HG	JI	LK
Linkage or E.M.F.	0	10	$17\frac{1}{2}$	20	$17\frac{1}{2}$	10	0	-10	$-17\frac{1}{2}$	-20	$-17\frac{1}{2}$	-10

In Fig. 11 the successive positions of the frame were drawn 30° apart, so that if we draw a series of radial lines all 30° apart and measure off the above lengths in any convenient units along the radii, corresponding to the respective positions of the frame, we shall obtain the required polar diagram. When this is done it is found that the points all lie on the circumferences of two circles as shown in Fig. 12, one of which corresponds to the positive values of E.M.F. and the other to the negative values as found above. This diagram is generally known as the Figure Eight, and is characteristic of all simple frame aerials when the dimensions of the frame are small compared with the wavelength.

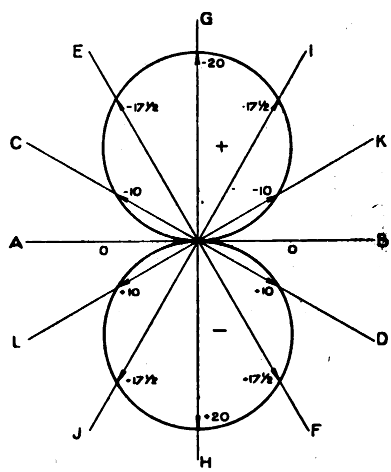


Fig. 12. *Polar Curve of Simple Frame as found from Diagram of Fig.* 11.

Equation of Polar Diagram of Simple Frame. (Figure Eight or Cosine Diagram). Referring now to Fig. 13, let AB be a plan view of the frame and let PO be the direction of incidence of the wave, making an angle θ with the plane of the frame. Bearing in mind that the

magnetic flux in the wave is at right angles to the direction of propagation, the maximum linkage is clearly when the angle θ is equal to 0° and AB coincides with PO. In the condition shown in Fig. 13 the linkage must be proportional to the projection of the frame on the line PO, and this is found by dropping perpendiculars A*a* and B*b* on the line POP′.

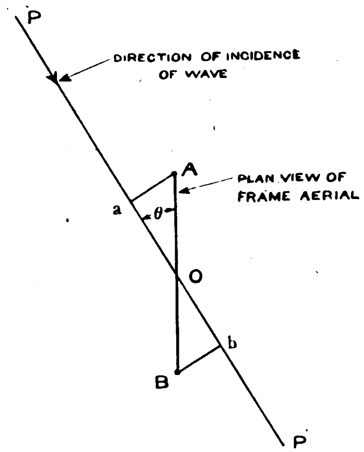


Fig. 13. *Theory of Cosine Diagram.*

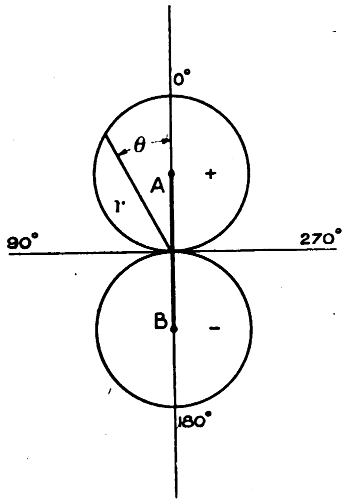


Fig. 14. *Theoretical Cosine or Figure Eight Diagram of Simple Frame.*

Now the length O*a* = OA cos θ and similarly O*b* = OB cos θ so that the total length *a b* is equal to AB cos θ and we may write the equation thus :—

$$r = R_{max} \cos \theta$$

where R_{max} is the radius of the curve when the plane of the frame is in the plane of propagation of the wave.

On plotting this curve as shown in Fig. 14, the figure eight diagram is again obtained, and since for all values of θ between the limits $\theta = 90°$ and $\theta = 270°$, cos θ is negative, we get the same result which was observed previously, namely that the one circle is negative and the other positive, corresponding to the change in direction of linkage through the frame and hence in E.M.F. as the frame passes through the position of zero linkage.

Maximum *versus* **Minimum Strength Signals for Direction Finding.** An important point in practical direction finding is the accuracy with which a bearing can be taken. A

reading may be made, either by noting the position of the frame when signals are strongest or by observing the direction of minimum signals. When the maximum strength is being observed, the frame is in the position HG (Fig 11 and Fig. 12) and an inspection of the polar curve will show that a small change of angle will make a very small change of signal strength. If on the other hand we take the position AB, it is clear that a similar small change of angle will make a large percentage change of signal strength, as the curve is very steep around this position. The minimum is therefore very much more sharply defined than the maximum, and it is possible to ascertain its position very accurately; hence it is customary in practice to arrange the direction finder so that at the instant of minimum signal strength, the pointer attached to the rotating support of the aerial, indicates on a circular scale, which is divided into degrees from 0° to 360°, the direction of the transmitting station.

SYSTEMS OF DIRECTION FINDING.

We have seen above that the directional properties of the frame aerial are invested in the vertical limbs of the frame, and in the early days of this type of reception a number of systems were evolved which consisted of combinations of vertical aerials arranged to give polar diagrams of reception very similar to the figure eight diagram described above. The modern systems, however, make use, almost exclusively, of frame aerials, and may be grouped under headings somewhat as follows:—

(1) Simple rotating frame aerials connected directly or through an intermediate circuit to an amplifier and detector.

(2) Combinations of frame aerials, fixed relative to each other but free to rotate as a whole and with or without switching arrangements for the summation of the aerial E.M.F.s.

(3) Large fixed frame aerials with an associated radiogoniometer (page 50) which enables the rotating part of the system to be reduced to small dimensions.

The frame aerial may also be used in conjunction with a vertical aerial for the production of a special form of polar curve which enables the determination of absolute direction or "sense," this being applicable both to the small rotating frames and also the fixed frame and radiogoniometer, as in the Marconi-Bellini-Tosi System (page 49).

The Simple Rotating Frame Aerial and Inherent Defects of Frame Aerials for Directive Reception. The frame aerials used in this type of D.F. are almost exclusively multi-turn and may be grouped under three main headings:—

(*a*) Box Form (Fig. 15).

(*b*) Pancake Form (Fig. 16).

(*c*) Combination of Pancake and Box aerials. This type of aerial is shown in Fig. 233, as applied to U.S. Navy design of aircraft D.F.

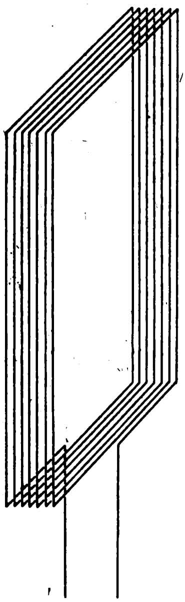


Fig. 15. *Box Form Frame Aerial.*

For reasons already stated in the Preface, it is not proposed to consider the details of the design of multi-turn frame aerials or the practical operation of the rotating frame D. F. For further information on these matters reference should be made to the numerous publications of other writers. Ref. (49), (55), (59), (70), (77), (84), (85), (88), (97).

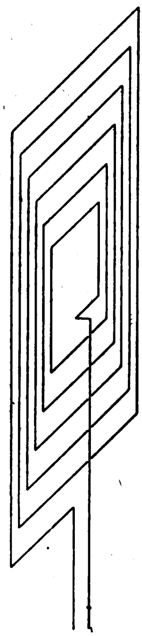


Fig. 16. *Pancake Form Frame Aerial.*

It is necessary to investigate, however, certain troublesome features of frame aerial reception which are common to all types of frame, both single and multi-turn and whether used as a rotating frame D. F. or as large fixed loops in conjunction with a radiogoniometer.

The circuit of the simple rotating frame direction finder will be as shown in Fig. 17, the aerial coupling coils being split for the insertion of the aerial tuning condenser and the secondary coil of the coupling being tuned by means of a further variable condenser across which is the amplifier and detector.

Although the theoretical polar diagram of a small frame aerial suggests at first sight a complete solution of the problem

of direction finding, a number of serious defects are discovered as soon as such an aerial is used for the purpose in practice, and being characteristics, the following remarks may be taken as being applicable to all systems of D.F. in which any type of frame aerial is used.

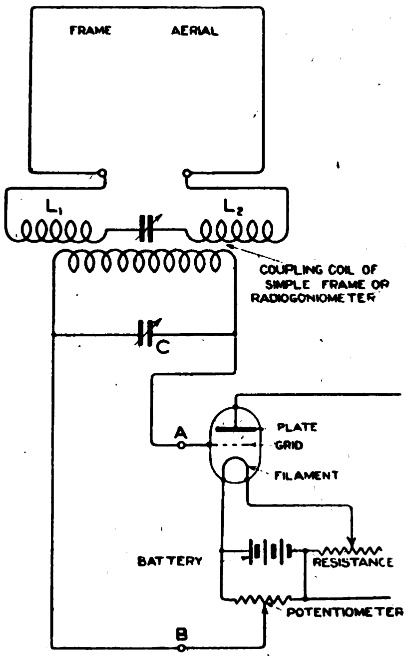


Fig. 17. *Circuit of Simple Frame D.F.*

Apart entirely from the distortion of bearings as a result of the phenomena of "Night Effect" (Chapter 6), the following curious effects are noticed :—

(*a*) The two minima are not 180° apart, but may be as much as 30° out of their true positions.

(*b*) The maxima are not of equal strength.

In Fig. 18 we have illustrated these effects on the polar diagram of a simple frame aerial. Curve AA is the normal figure eight diagram for the intensity of the reception from various directions, by the frame aerial in the position a b, the true minima being, of course, in the directions 90° and 270°. Curve CC shows the abovementioned distortion. In the latter curve it is seen that the amplitude of the maximnm at 0° is much greater than at 180° and that the two angular positions of the zero E.M.F. are at 105° and 255°.

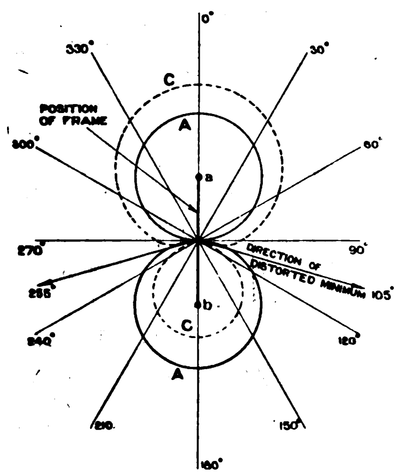


Fig. 18. *Figure Eight Diagram Distorted by Vertical.*

The distortion is due to two causes :—

(*a*) The tendency of the loop aerial to oscillate direct to earth as a vertical wire, through the capacity of the receiver. (This phenomenon has been called "**Antenna Effect,**" **Vertical Component,**" **or** simply "**Vertical.**")

(*b*) Direct reception of signals on the receiver circuits (known as "**Direct Reception**" or "**Direct**").

Vertical Component. This is a most insidious trouble and occurs very frequently, so that the following description of how it arises should be particularly noted. Consider the diagram of the rotating frame aerial D.F. in Fig. 17. In this case we have shown the aerial, tuned by means of the variable condenser, inserted in the split inductances L_1 and L_2 which may represent either the coupling coils of the rotating frame or the field coils of a radiogoniometer. L_1 and L_2 are coupled magnetically with the jigger secondary, which is tuned to the wavelength of the frame by another adjustable condenser. The grid of the first valve of the amplifier is connected to one side of this jigger condenser, the other side being joined to the filament batteries, etc. (See Chapter 3.) Now the grid of the first valve has a certain capacity to earth, but owing to the fact that its dimensions are very small, its capacity is also minute. On the other hand, the batteries being usually bulky, and often standing on the floor of the receiving room, have (compared to the grid), a large capacity to earth. There is also a certain capacity between the coils L_1, L_2 and the jigger secondary.

Omitting magnetic couplings, the circuit can be redrawn as in Fig. 19, the above-mentioned natural condensers being shown specifically by dotted lines. B now represents the capacity of the batteries to earth, and G that of the grid. We have drawn B large compared to G to emphasise the difference in their capacities to which we have referred. The condenser F represents the capacity between the coils L_1, L_2 and the jigger secondary.

We have seen that the E.M.F. acting round a loop is the resultant of two E.M.F.s in the vertical legs. A study of the sine curve of Fig. 10 will show that these E.M.F.s are, most of the time, acting together either up or down the sides ; and also that they are very much larger in value than the loop E.M.F. which is always given by their algebraic sum *round the frame.* The effect of these E.M.F.s is to produce an

alternating potential difference between the loop aerial, as a whole, and earth. This potential will cause a current to flow through F, then branching down the inductance of the winding, part flowing through B to earth and part *via* G. (Fig. 19.)

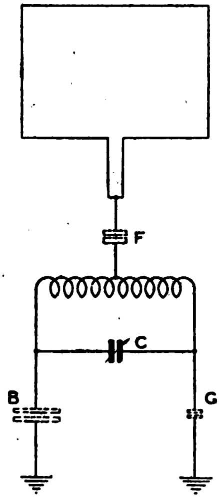


Fig. 19. *Cause of Vertical.*

Now the distributed capacity between L_1, L_2 and the jigger secondary is more or less uniform along the windings, and hence we may assume that our "phantom" condenser F is connected to the middle point of the jigger secondary. The impedances of the two paths to earth *via* B and G are clearly very different, owing to the fact that their capacities are widely divergent, and hence the currents which flow in them will not be equal in value. Owing to these differing currents the fall in potential through the winding from mid-point of the jigger secondary to the top plate of B will not be the same as that to the top plate of G, and therefore a difference of potential will exist between the terminals of the variable tuning condenser C.

This parasitic potential across C will cause a current to flow round the jigger secondary circuit and will, of course, give signals when amplified and rectified.

We thus see that the existence of vertical component results in the circuit as a whole possessing receiving power which is quite independent of the orientation of the loop or any magnetic couplings between the loop and its associated circuits.

Direct Reception. Before proceeding to the exact effect of vertical component on the direction finder, the second cause of error mentioned above must be examined. The oscillatory circuits of any receiver consist of inductances wound in the form of coils and shunted by condensers. These coils are really tiny aerials and consequently will receive signals weakly; any such reception being quite independent of the aerial. The polar curve of the loop aerial will, consequently be modified more or less according to the intensity of the reception on the amplifier, jigger, etc., comprising the receiving circuits. In the case of very small rotating frame

aerials, the direct reception (*i.e.*, reception on jiggers, etc.) may be quite comparable with the reception on the loop, and large distortions result.

Polar Diagram of Figure Eight Distorted by Vertical and Direct. The gross result of vertical and direct is to enable the incident wave to apply an E.M.F. to the A and B terminals of the amplifier, which E.M.F. is more or less independent of the direction in which the loop is pointing. We shall now examine how the resultant polar diagram may be built up for the case of a simple loop aerial and receiver in which we have :—

(*a*) The E.M.F. induced by the wave in the aerial and which varies with the angle between the plane of the loop and the direction of incidence of the wave, and which, as explained on page 26 gives the normal figure eight diagram.

(*b*) An E.M.F. due to vertical and direct, which is independent of the angular relationship between the loop and wave, the polar diagram of which, as we saw on page 19, is a circle.

We have shown these two diagrams in one picture in Fig. 20.

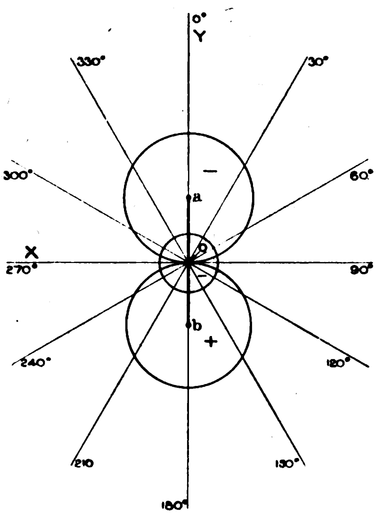


Fig. 20. *Figure Eight Diagram of Frame with Circle Diagram of Vertical.*

Here, the two large circles which are tangential to the line OX and whose centres lie on OY are the figure of eight of the frame aerial a b, and the small circle with its centre at O is the ordinary circle diagram of the vertical and direct. If we assume that the E.M.F.s induced in the frame and receiver by vertical and direct are in phase, then it is clear that the total E.M.F. induced in the circuit as a whole will be given by the algebraic sum of the component E.M.F.s for any particular orientation of the frame.

On page 24 we showed that the phase of the E.M.F. induced in a loop, abruptly shifts through 180° when the frame moves through the minimum position, whilst no such shift can occur in the case of the vertical wire. Consequently, when we are adding the smaller circle to the larger circles of Fig. 20 we must regard one circle as being positive in sign and one negative, and the small circle as either uniformly positive or negative. The choice of signs is purely arbitrary and we have marked the upper large circle negative, the lower one positive, and the small circle negative. If now the polar co-ordinates are added graphically, it is found that the complete diagram is that illustrated in Fig. 18, curve CC.

Displaced maxima and unequal minima are commonly observed in practical direction finding, although the exact result may be modified by lack of correspondence in phase between the loop E.M.F. and the vertical E.M.F. In general, if the phases happen to be nearly coincident, the minima are sharp but displaced, as shown in Fig. 18, but if the phases differ, the minima are more or less displaced but are impure (*i.e.*, signals are audible at all positions of the loop). The polar diagram of a frame aerial plus out of phase vertical is shown in Fig. 21, where it will be seen that no actual zero of signals occurs at any place. If a direction finder suffers from much out of phase vertical, it will be readily understood that it is very difficult to take directions at all, but it is important to notice that *if the minima are fairly pure, then the mean of the scale readings of the two displaced minima is the correct direction of the true maximum.*

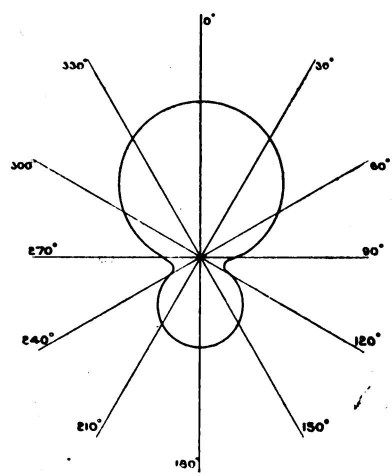


Fig. 21. *Figure Eight Diagram distorted by "Out of Phase Vertical."*

Although the distortion of the figure eight diagram is a disadvantage in simple direction finding, it is actually the basis of the most common method of obtaining the "absolute direction" or "sense" of incoming signals.

Reduction and Elimination of Vertical and Direct. The methods of reducing or eliminating vertical and direct may be divided into three classes.

(1) Increase of receiving power of aerial.

(2) Arrangement of the circuits so that vertical is weakened.

(3) Screening.

The amount of distortion produced is dependent upon the relative strengths of the reception on the aerial and the reception by vertical and direct; a study of the diagram Fig. 18 will make this clear. From this figure, it can be seen that the larger the radius of the small central circle as compared with the diameter of the circles of the figure of eight diagram, the more the two minima will be displaced. We must, therefore, make the figure of eight diagram as large as possible compared with the vertical diagram.

Now the intensity of the vertical reception varies approximately as the linear dimensions of the aerial, whereas the receiving power of the frame is proportional to the square of the linear dimensions, and so the larger we make the frame, the less noticeable will be the effect of the vertical. A similar line of reasoning also applies to the case of direct reception, the intensity of which is clearly quite independent of the size of the aerial, so that we may make the aerial reception as large as we like, by comparison, by simply increasing its size.

There are several methods of reducing vertical in the circuits themselves.

Grid Condenser or "Compensator" Method. We have seen that vertical is due to the unbalanced capacity to earth of the grid of the first valve of the amplifier and the filament batteries. The most immediate way of correcting the trouble is to make these two capacities exactly equal. This can be done by connecting a small condenser from the grid of the first valve to earth, which is equivalent to putting a condenser in parallel with G (Fig. 19). This is adjusted in value until the total capacity of G and the extra condenser is equal to B. When this state of affairs exists there can be no potential induced across the condenser C because the two parallel paths to earth have identical impedance.

Earthed Mid-Point of Coupling Coils. Another method is to apply an earth wire to the mid-point of the aerial coupling coils. By this means the potential of the coils is kept zero

with respect to earth at all times. This being so, no potential difference can ever exist across the condenser F (Fig. 19) and consequently no current flows through B and G, thereby avoiding the creation of an E.M.F. across the condenser C. The mode of applying the earth to the mid-point of the coupling coils is shown in Fig. 22, where it will be observed that the aerial is broken at the top and leads are brought out for the insertion for a series variable condenser. The two halves L_1, L_2 of the coupling coils are directly joined in series and the mid-point connected to earth.

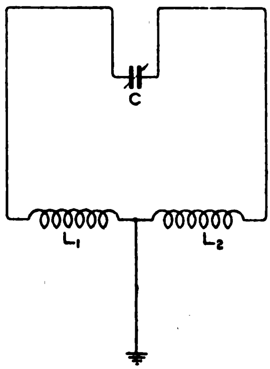


Fig. 22. Earthed Mid-Point of Aerial Coupling Coils.

This method is very effective, but not perfect in practice. The residual vertical is due to two causes :—

(1) Imperfections in the earth connection and also the inductance of the earth lead allow the coils to vary slightly in potential.

(2) Owing to the inductance of the two halves of the coils, even if the centre points are at zero potential, the ends of the coils may not be so.

The method is therefore generally used in conjunction with other means and is regarded more as an additional safeguard than a positive cure.

The Shielded Transformer. The most definite solution of the problem at present discovered is afforded by the "shielded transformer," the system being shown in Fig. 23. Here we have shown an aerial tuned by a variable condenser C_1 connected between the two halves L_1, L_2, of the coupling coils. S is the secondary which is connected immediately to the primary winding P of a transformer, the secondary J being shunted by the condenser C_2. The transformer PJ is very tightly coupled, the coil J being, in fact, wound on top of P on an ebonite tube. Under these conditions the whole system SPJ can be effectively tuned by means of the condenser C_2. Between the windings P and J, a copper foil shield E is interposed ; this shield is metallically connected to the B terminal of the amplifier, which may be earthed. The exact arrangement of the shield and windings will be clearly understood by reference to Fig. 179.

Now we have seen that vertical component is due to electrostatic coupling between the aerial and jigger circuits. The presence of the shield E, which is maintained at zero—or nearly zero—potential, provides an effective block against any such coupling, since an electrostatic field cannot pass through a conductor.

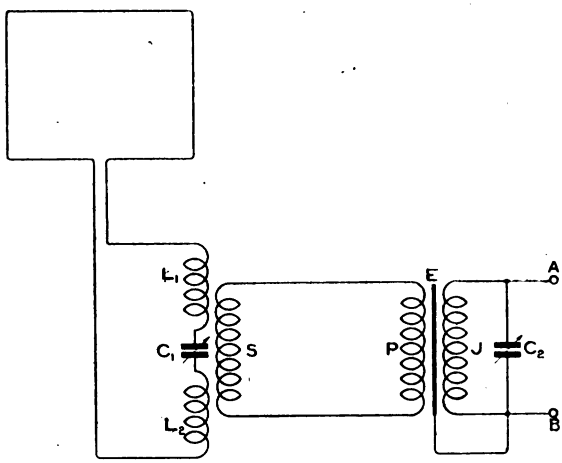


Fig. 23. *The Shielded Transformer.*

This method of eliminating vertical is most effective, and is indeed the only satisfactory solution of the problem in the case of the Marconi-Bellini-Tosi " Aperiodic Aerial " system, which is discussed later in this chapter.

Elimination of Direct. In order to prevent direct reception on the coils and amplifier, it is necessary to enclose all the apparatus in earthed metal boxes. An electro-magnetic wave cannot penetrate a conducting sheet and the method is quite effective. If the boxes are small they should be completely enclosed on all sides, as strong signals will act on a jigger if the lid of the screening box be slightly opened. In order to overcome the difficulty of adjusting apparatus which is boxed up in this manner, permanent stations which employ the small rotating frame aerial D.F. are generally provided with a screened operating room. Such a room may be built of copper or galvanised iron sheeting, the windows, if any, being made with metal gauze.

An additional precaution often taken is to wind all coupling coils and jiggers in the receiving apparatus in sections and

arrange them astatically, thus ensuring that whilst the necessary mutual inductance exists between any pair of coupling coils, their net coupling to the field of an electromagnetic wave is zero.

Displacement Current Effects. The error to which this name has been given is always present in box pattern multi-turn frame aerials. When such a frame is placed in the theoretical position of zero reception (that is to say, with the plane of the turns at right angles to the direction of propagation of the incoming wave), the vertical limbs of the successive turns are spaced in the direction of propagation of the wave and will, therefore, have E.M.F.s of varying intensities induced in them. Between the successive turns there is also an appreciable capacity, and so a sort of second phantom loop circuit is formed which has its plane at right angles to the plane of the actual frame aerial. This loop is clearly in the position of maximum reception, with the result that an E.M.F. is set up between the terminals of the frame which is in phase with the signal E.M.F. in the frame. Owing to the fact that this phantom loop is not tuned to the frequency of the incoming wave, the displacement current which flows will be approximately 90° out of the phase with the E.M.F. and will give rise to errors very similar to those of "out of phase Vertical." Unlike Vertical, the Displacement Current error changes sign when the coil is rotated through 180° since in this case the phantom loop has also swung through 180°; actually the change in sign takes place at the instant of maximum reception by the frame, at which instant the displacement current is zero.

With a pancake coil construction, the Displacement Current effect is absent, since in the position of minimum signal reception all the vertical limbs of the frame are in the same plane and parallel to the wave front. On the other hand, the pancake coil has a greater capacity to earth than the box form of coil of the same receiving power, and so is more prone to the effects of Vertical. A point which enters into the design of multi-turn frames is that the product of Area of Frame into Number of Turns (area-turns) shall be the maximum possible for any given natural wavelength of the coil, and a type of construction which has been found to give this result is a combination of the box and pancake coils in which a number of pancake coils are placed side by side and connected in series. Since the capacity of such a coil is less than it would

be for a single pancake coil of equal area-turns, the Vertical is less pronounced, whilst at the same time the Displacement Current effect is less than it would be for a box construction. Remembering that the displacement current and Vertical produce similar effects in the circuit and that the former changes sign whilst the latter does not, it will be seen that the above combination of pancake and box frames offers an opportunity of balancing the one effect against the other and so obtaining a partial solution of the double problem (59), (84). The actual effect upon the figure eight diagram of a circuit in which "out of phase Vertical" is balanced against Displacement Current Effect, is to make one of the minima comparatively sharp and the other one extremely flat, and hence to make "Sense" determination possible to some extent.

THE DETERMINATION OF "SENSE" OR ABSOLUTE DIRECTION.

The Cardioid, Heart-shape or Apple Diagram of Reception. We have seen that two minima are obtained with a frame aerial, both in the case of rotating frame and in the Bellini-Tosi aerial system with a radiogoniometer, so that supposing a reading of 45° is obtained on some station, then there will be another minimum of $45° + 180° = 225°$ and it is quite impossible, *à priori*, to decide which is the real bearing of the station. In many cases, such information is not necessary, external evidence indicating which is the reading to take, but it often happens that the knowledge would be very valuable, and so modern direction finding installations are equipped with means of determining "sense."

In the discussion of vertical component and its effect on the polar diagram of a frame aerial, a method was shown of obtaining the complete polar curve of the two aerials, whose effects are superimposed by drawing the polar curves of the two systems on one diagram and then adding graphically the ordinates of the two curves and obtaining a third curve compounded of the two original components. Now let us consider a circuit in which the effect of a vertical wire aerial is combined with a frame, and in which, by some means, we have made adjustments so that the effect due to the maximum current induced by the signal in the frame (*i.e.*, when the plane of the frame coincides with the direction of the transmitting

station), is just equal to that due to the current induced by the same signal in the vertical aerial. In this case the circle representing the polar diagram of the open aerial will have a radius equal to the diameter of one of the circles of the figure eight diagram of the frame. We have illustrated the condition in Fig. 24, the plane of the frame lying along XOX^1 and the two small circles having diameters On and Om forming the usual figure eight. The large circle $m\,p\,n\,q$ is the circle polar diagram of the vertical aerial, and its radius has been made equal to the diameters On Om of the figure eight circles.

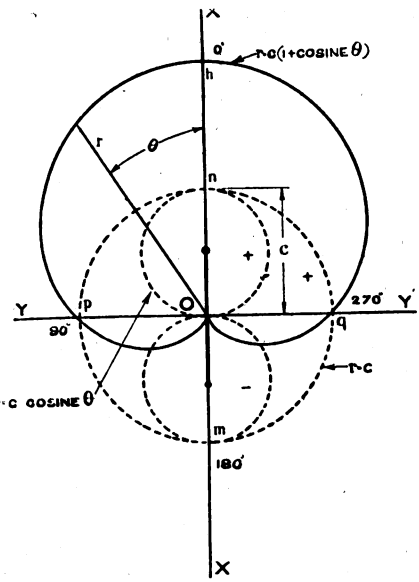


Fig. 24. The Heart-shaped Diagram.

The currents whose intensities are represented by the radii of the diagram in Fig. 24 are alternating, and consequently it must be assumed that they are either in phase or 180° out of phase in order that their resultant may be obtained by simple addition or subtraction of the radii. Further, it was seen when considering the induction of an E.M.F. in a frame that the phase of the E.M.F.—and hence of the current—shifts 180° when the frame is turned through the minimum position. It will therefore be necessary to adopt a convention of signs for the diagram in order that addition or subtraction may be performed according to whether the phases of the vertical aerial and loop currents coincide or are 180° different. In Fig. 24 the lower circle of the figure eight has been called negative, the upper being therefore positive, and the large circle of the vertical aerial is also positive. The reader should understand that the actual signs adopted are immaterial, so long as the signs of the two figure eight circles are opposite. We shall see later that the sign of the vertical aerial or both

signs of the frame, can be reversed by a reversal of coupling in the receiving circuits.

We are now in a position to consider the diagram of the combination. The intensity of the resultant current induced by a wave arriving from any given direction is given by adding or subtracting the radii of the two polar curves lying in that direction, according to whether the signs are like or unlike. We can at once see where four points on the new curve will lie.

(1) In the direction OX the radii are equal and are both positive in sign, therefore the curve passes through the point *h* such that O*h* is equal to twice O*n*.

(2) Along OY there is zero current in the frame and hence the curve passes through *p*.

(3) In the direction OX^1, the radii are equal and opposite in sign and therefore the resultant current is zero and the curve will pass through O.

(4) Along OY^1 there is again zero current in the frame so that the curve passes through *q*.

Intermediate points may be filled in by performing the necessary additions and subtractions with the aid of a pair of dividers and on joining up all the points so obtained, by a smooth curve, the heart-shaped polar curve shown by the full line will result. This diagram is extremely important, as it is the basis of all present-day methods of determining sense.

It will be seen that the system possesses only one minimum and that the maximum is 180° away from the minimum, so that there is now no ambiguity as to what is the sense of the direction of the transmitting station. If the frame (or search coil of the radiogoniometer) be rotated, only one point can be found on the scale at which the signals vanish. It should also be noted that the maximum of the heart-shape is twice the strength of the maximum of the frame aerial alone, and further, that whereas the minima of the frame lie along YOY^1, the minimum of the heart-shape diagram is along OX^1; *i.e.*, in the *plane of the frame* and 90° away from the minima of the frame itself.

Equation of Heart-shaped Polar Diagram. We have seen that the equations of the vertical and frame aerials are as follows :—

Vertical :— $r_v = \text{Constant.} = C$ (Fig. 24).

Frame :— $r_f = R_{f\,max} \cos\theta$

where $R_{f\ max}$ is the radius of the polar curve when the frame is in the position of the maximum induced E.M.F.

In the combination of vertical and frame E.M.F.s to give the heart-shape diagram, we make $r_v = R_{f\ max}$ (see Fig. 24) and also adjust the phases of the two E.M.F.s to coincide, so that the equation of the heart-shape diagram may be found from the simple algebraic addition of the two component equations thus :—

$$r_h = r_v + R_{f\ max} \cos \theta$$
$$= r_v (1 + \cos \theta)$$
$$= C (1 + \cos \theta). \quad \text{(Fig. 24).}$$

The single zero value and the single maximum of double the maximum amplitude of either component, result from the fact already mentioned that $\cos 0° = 1$ but $\cos 180° = -1$.

Hence, for $\theta = 0°$ $r = r_v$ $(1 + 1) = 2\ r_v$

whilst for $\theta = 180°$ $r = r_v$ $(1 - 1) = 0$.

The Heart-shape Circuit. The addition or subtraction of the currents in the two aerials is performed electrically by means of couplings. In Fig. 25 are shown three inductances, the coils 1 and 3 being both coupled to the coil 2. In such a case the E.M.F. induced in 2 by the coil 1 will be proportional to the intensity of the current in 1; similarly, the E.M.F. induced by the current in 3 will be proportional to the intensity of that current. The total E.M.F. in 2 is given by the algebraic sum of these two E.M.F.s, being equal to the difference of the two if they are 180° out of phase and their sum if they are in phase. Therefore the E.M.F. in 2 is proportional to the algebraic sum of the currents in 1 and 3, and since the current is proportional to the E.M.F. it is also proportional to the sum of the two currents, 1 and 3. Such a combination of coupling thus affords us a means of electrically adding or subtracting individual alternating currents.

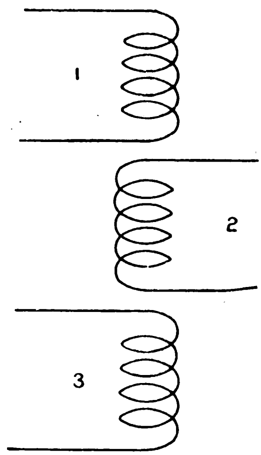


Fig. 25. Addition of E.M.F.s by Couplings.

It is, therefore, only necessary to include coil 1 in the circuit of the vertical aerial and coil 3 in that of the frame, when we shall have an E.M.F. in (and hence a current in the circuit

of) coil 2 which is proportional to the ordinates of the dotted polar curve of Fig. 24 for various angles of incidence of the incoming wave.

In all the foregoing discussion we have assumed that the E.M.F.s (and currents) in the vertical wire and frame were in phase. This assumption is not correct. We have seen on page 17 that the E.M.F. induced by a passing wave in an open

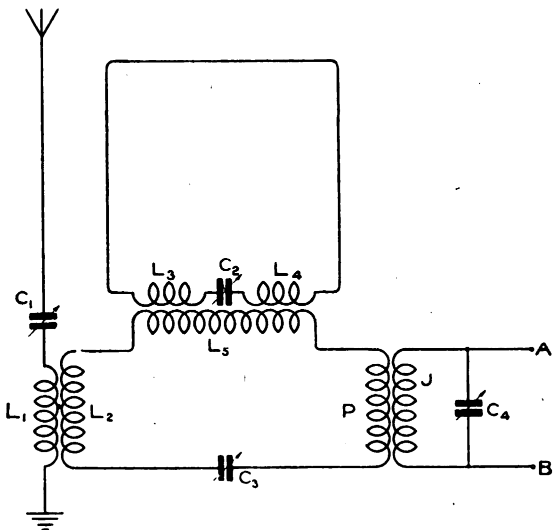


Fig. 26. Heart-shaped Diagram by Tuned Open and Frame Aerials with Tuned Intermediate Circuit.

aerial is in phase with the flux in the wave, whereas in the case of a loop aerial it was explained on page 22 that the E.M.F. is 90° out of phase with the flux in the wave. We cannot change the relative phases of these E.M.F.s because they are inherent in the receiving properties of the frame and vertical aerials. We can, however, shift the phase of the current which flows as the result of an alternating E.M.F. by altering the reactance of the circuit, and as is pointed out on page 54, the phase of the current in an aerial can be shifted by changing the tune of the circuit very slightly. We can therefore bring the two currents in the vertical and loop aerials into step by a suitable adjustment of the tune of the circuits.

Fig. 26 illustrates a circuit which fulfils these conditions. The vertical aerial is tuned by means of the condenser C_1

and the inductance L_1 to the wavelength to be received. The frame aerial is tuned by the condenser C_2 and the split inductance L_3, L_4. The common intermediate circuit L_2, L_5, P is tuned by the variable condenser C_3 and is coupled by the coil P to the jigger secondary J; the A and B terminals of the amplifier being connected across the terminals of the secondary tuning condenser C_4. The summation of the currents in the aerials is carried out in the intermediate circuit and their relative effects are controlled by the values of the couplings of this circuit to the two aerials. The necessary phase adjustments are obtained by the tuning adjustments of the condensers C_1 and C_2.

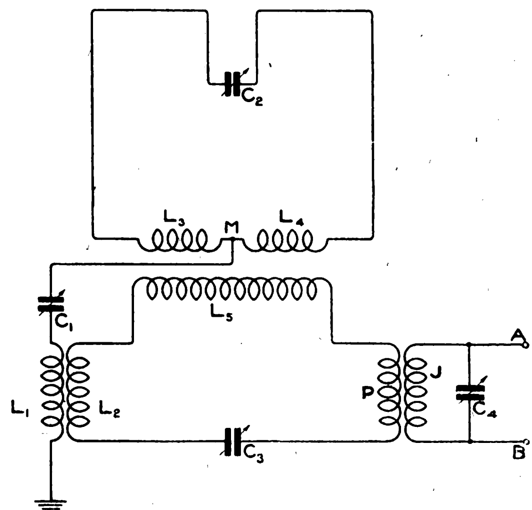


Fig. 27. Method of Avoiding Separate Open Aerial.

There is no necessity to use a separate wire for the vertical aerial. In Fig. 27 is shown a circuit in which the principle of earthing the mid-point of the coupling coils is used for this purpose. In Fig. 22 this was illustrated as a method of reducing the effect of vertical, but here the vertical is actually used to supply the required open aerial E.M.F. The incoming wave will induce an E.M.F. between the frame aerial, taken as a whole, and earth and, this E.M.F. will cause an alternating current to flow from the mid-point M to earth through the condenser C_1 and the coil L_1. This current in the frame aerial will divide at M, and half will flow through

L_3 and half through L_4 since the aerial is symmetrical in every way. Since these two currents are in opposite directions through L_3 and L_4 there will be no resultant magnetic field produced in L_5 and the amplitude of the E.M.F. induced in the intermediate circuit may be controlled entirely by the coupling of L_1 and L_2, and the phasing by C_1 and C_2 as before.

Phase Adjustment of Heart-shape with Tuned Aerials. Let us now consider the adjustment of the circuit of Fig. 27 with the aid of a vector diagram showing the phase relations of the E.M.F.s and currents in the two aerials. In Fig. 28

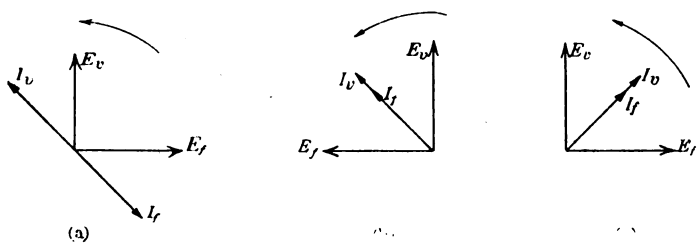


Fig. 28. Theory of Circuit for Tuned Heart-shaped Diagram.

E_v represents the E.M.F. in the vertical aerial, which we know to be in phase with the flux in the wave (page 17), and E_f is the E.M.F. in the frame aerial which lags 90° on the flux in the wave. (Assuming counter clockwise rotation of vectors.) Now suppose we adjust C_1 (Fig. 27), so that the current in the open aerial *leads* 45° on the E.M.F.; this is illustrated in Fig. 28 (*a*) by the vector I_v. Further, C_2 is adjusted so that the current in the frame ***lags*** 45° on the E.M.F. in the frame; this is represented by the vector I_f, which is seen to be in phase opposition with I_v. By means of the couplings between the two aerials and the intermediate circuit, these two equal currents can be arranged to induce E.M.F.s in the intermediate circuit, which are equal in amplitude and in opposite directions round the circuit, giving the condition of zero signals, which is taken to indicate sense, when using the heart-shape circuit.

Reversal of Sense. Two possibilities exist whereby an incorrect sense indication may be given owing to mistakes in the adjustment of the circuit, namely, reversal of a coupling, and incorrect phasing of the aerial circuits.

Reversal of a Coupling. Suppose that when the circuit is correctly balanced, the coupling L_5 be reversed, either by changing the connections over or by actually turning the coil round. This process means that we reverse *at every instant* the direction of the E.M.F. induced in the intermediate circuit by the frame aerial, and this corresponds to a 180° change in phase. In this case, instead of the diagram of Fig. 28 (*a*) we get that of Fig. 28 (*b*), where I_f is now in phase with I_v, so that the heart-shape maximum is obtained. In order to get a zero balance without further alteration to the circuit, the frame aerial will have to be rotated through 180°, which is the equivalent to a reversal of sense.

Incorrect Phasing. Suppose that having adjusted the phase of the vertical aerial so that the current leads 45°, and that of the frame aerial so that the frame current lags 45°, it is found that a correct sense indication is given. Now imagine these phase conditions to be reversed by slight mistuning, so that the current in the vertical aerial *lags* 45°, and that of the frame *leads* 45°, then, as shown in the vector diagram of Fig. 28 (*c*), I_v and I_f are again in phase and, just as in the above case, a reversal of sense again occurs.

The danger of a reversed sense bearing in the case of a ship D.F. installation, and the combination of difficulties attached to the operation of the heart-shape circuit with tuned aerials, led to the development of a method of phasing which gives far more stable conditions. Whilst applicable to the simple rotating frame, this method of "**resistance phasing**" was developed in connection with the Marconi-Bellini-Tosi system and is described on page 64.

THE ROBINSON (R.A.F.) SYSTEM.

Whilst the method of taking bearings on the minimum signal strength has been seen to have advantages from the point of view of sensitiveness, there are certain specialised applications of the direction finder in which it is preferable to have fairly strong signals at the instant of taking the bearing. An example of this is in aircraft installations where the noise of the engines makes it difficult to work with very weak signals. In some cases it may be required to read the transmitted signals throughout the process, which is impossible when the intensity passes through a zero value.

A system which obviates this defect is that due to Capt. J. Robinson, in which the bearing of a station is indicated by a minimum value of signal strength, but this minimum is not a zero point. The method consists essentially in the use of two frame aerials fixed at right angles to one another, the system being free to rotate in a vertical plane (see Fig. 29). One of these frames is known as the Main Coil, and at the instant of taking the bearing, this aerial is in the plane of the incoming signal; that is to say, the induced E.M.F. is a maximum. The second frame is called the Auxiliary Coil and has no E.M.F. induced in it under the above circumstances. If, therefore, switching arrangements be provided whereby the auxiliary coil may be placed in series with the main coil, first in one direction and then in the other, no appreciable difference should be observed in the resultant E.M.F. of the two frames from that induced in the main coil alone, as indicated by the strength of signals in the telephones. The aerial system is tuned to the wavelength of the incoming wave by means of the variable condenser and the signals are amplified and received in telephones in the ordinary way.

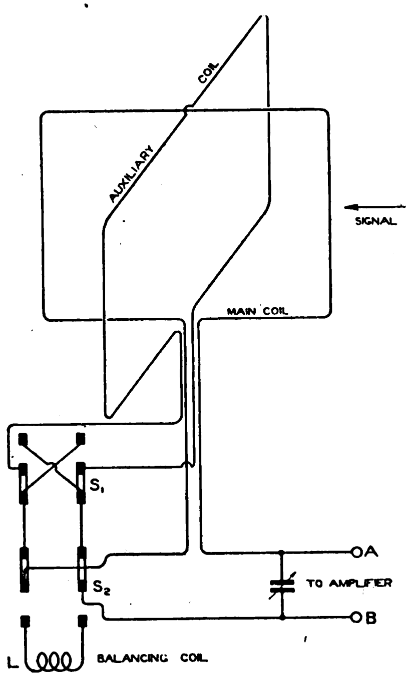


Fig. 29. The Robinson D.F. Circuit.

Fig. 29 shows the circuit in diagrammatic form in which the switch S_1 is arranged to reverse the auxiliary coil when it is in series with the main coil and the switch S_2 disconnects the auxiliary coil and replaces it by a balancing inductance L, which is given such a value that the circuit is not thrown out of tune when receiving on the main coil alone. A transformer is inserted in the leads to the amplifier, which prevents

the grid of the first valve of the amplifier being isolated during switching operations, with consequent telephone noises.

Fig. 30 shows the plan views of the two frames at right angles, together with the polar diagrams of reception of each. If, now, the direction of the incident waves corresponds exactly with the maximum of the main coil, then the E.M.F. induced in the main coil will be proportional to the ordinate Om and there will be no E.M.F. in the auxiliary frame. Suppose, on the other hand, the direction of incidence of the wave makes a small angle θ with the plane of the main coil, then the E.M.F. in the main coil will be Om', which is practically equal to Om, and the E.M.F. in the auxiliary frame will be Oa'. On alternately adding or subtracting the E.M.F.s in the two coils, the resultant will vary from Or^1 to Or, the difference being equal to twice the E.M.F. in the auxiliary coil.

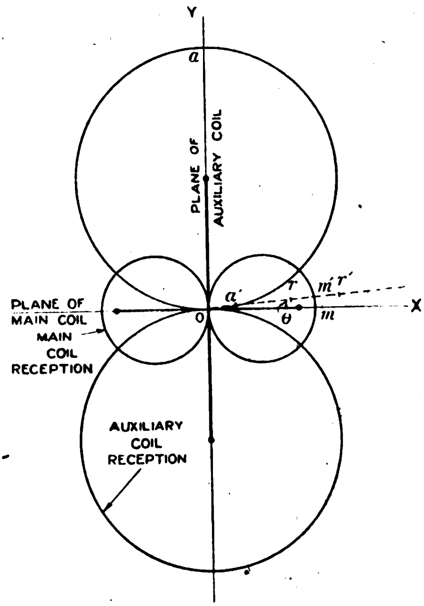


Fig. 30. Theory of Robinson D.F.

The sensitiveness of the method depends on what is the smallest ratio of $\frac{Or^1}{Or}$ which can be detected by the human ear, and some further notes on this point will be found in Chapter 9 when discussing the application of the system to aircraft D.F. working. Clearly, the directive properties are vested in the auxiliary coil, and the greater the receptive power of this coil is made relative to the main coil, the greater will be the ratio of $\frac{Or^1}{Or}$ for a given angle θ. Practical considerations in aircraft work limit the ratio of receiving powers of the two frames, and in Fig. 30 the E.M.F. in the auxiliary coil has been taken as two and a half times that in the main coil.

Errors. Troubles due to Direct Reception and Vertical are experienced for the same reasons that have already been stated in connection with the simple frame, although the effects are modified in some respects, and the methods which have already been described for eliminating the errors are adaptable, in general, to this system.

The portion of the direct reception on the main coil connections or transformer primary, which is in phase with the signal E.M.F. serves only to increase the main coil maximum signal intensity and does not affect the accuracy of the bearing. Direct reception on the auxiliary coil leads will produce errors, since, even when the coil is at right angles to the direction of the incident waves, there will be a residual E.M.F. across the reversing switch terminals.

Vertical gives blunt minima when out of phase with the signal E.M.F.; if in phase, it results in the auxiliary coil minima being less than 180° apart, with consequent error.

Direction Finding with the Robinson System. The unequal receiving powers of the two coils, whilst improving the sensitiveness of the apparatus, may lead to difficulty in its operation owing to a certain ambiguity which may possibly arise. The original method of taking a bearing was to obtain approximately maximum signals on the main coil, with the balancing coil in series, and then to throw the switch S_2, Fig. 29, and find the exact maximum point by means of the reversing switch S_1 in the manner described above. Since some difficulty is always found in ascertaining the position of the maximum signal strength of the main coil, it may happen that when the auxiliary coil is switched in, the methods of balancing mentioned above do not give the desired results. Fig. 31 has been drawn to illustrate this in a rather exaggerated degree. Suppose that in an attempt to find the main coil maximum, the frames have been rotated until the direction of the incident wave is along the line PO, then on switching in the auxiliary coil and operating the reversing switch, the signal intensities will be proportional to Or_1 and Or_1'. On rotating the coils back towards the main coil maximum so that the incident wave arrives along the line P'O, the signal ratios on reversal become Or_2 and Or_2', which are seen *both* to be less than before, and also, since r_2 has now fallen almost to zero, the discrepancy between the two signal intensities is much more pronounced. If the operator fails to realise the

cause of this, he will, instead of continuing to rotate the coils *through* the zero position for r_2, turn the coils in the opposite direction in an attempt to get a closer agreement between r and r', and after passing through positions P″O, etc., will eventually obtain an exact balance of r and r' at OY.

In this case the whole circuit is reversed, the main coil and auxiliary coil have changed functions and a 90° error results.

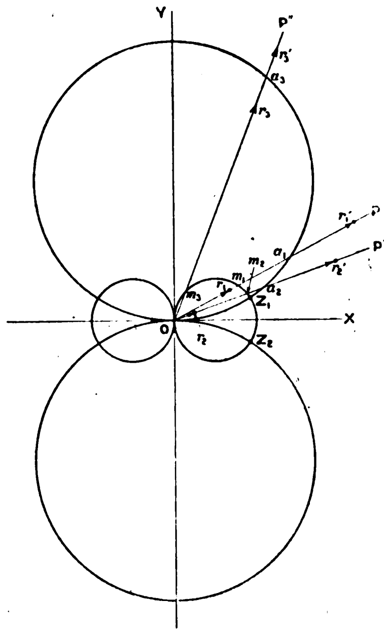


Fig. 31, *Ambiguity of Robinson D.F.*

Avoidance of 90° Ambiguity. All chance of 90° ambiguity can be avoided by ensuring that the approximate main coil maximum is located, in the first place, within the arc bounded by OZ_1 and OZ_2 in Fig. 31, the points Z_1 and Z_2 being where the main and auxiliary coil E.M.F.s are equal and a zero signal is obtained on reversal.

Instead of searching first of all for the main coil maximum, therefore, the reversing switch should be thrown first in one direction and then in the other, and the positions of the two minima noted. The required bearing will be midway between these two minima and can be found in the usual way. This method of taking bearings renders the balancing coil and the switch S_2 unnecessary, as the auxiliary coil is never out of circuit (49), (50), (55), (59), (70), (84), (125), (128).

THE MARCONI-BELLINI-TOSI SYSTEM.

The small rotating frames have many points in their favour for direction finding, and would be more universally used were it not for the fact that a number of difficulties arise when they are put into practical operation.

(1) It is almost impossible to take rapid "snap" bearings, owing to the weight of the frame aerial. In the case of a ship installation, this is important when working in congested areas, as coast stations will not make signals for D.F. work when engaged on other traffic, and bearings must be taken rapidly as opportunities arise. Similarly, in war time, bearings of enemy stations have to be taken with promptness and decision when the duration of the transmission is extremely short.

(2) For the above reasons it is necessary to make the frames small, and this means high amplification of signals to give a reasonable range. Valves are costly to maintain, and also the combination of low reception by the frame, and high amplification, increases the effect of direct reception on the receiving circuits.

(3) The elimination of "vertical" is found to be more difficult when using small frames.

(4) The small rotating frame is less amenable to correction for "quadrantal error," (see page 258) and it is customary to supply an "error chart," to which reference must be made in the case of every bearing observed.

With a view to mitigating some of the defects, a system was devised by Bellini and Tosi and has been extensively developed by the Marconi Company. In this system, instead of rotating the complete aerial in order to determine the direction of the incoming signal, the electro-magnetic waves induce E.M.F.s in a system of large frame aerials and the resulting currents are arranged to produce a magnetic field in a small instrument, the plane of which field corresponds to the plane of the field in the incident wave.

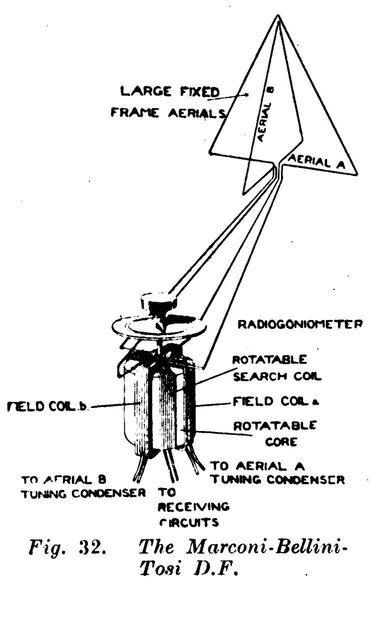


Fig. 32. The Marconi-Bellini-Tosi D.F.

The method consists in employing two directional loop aerials, fixed at right angles, and connected respectively to two similar coils, also at right angles, one to the other. A

third coil is arranged to rotate in these two latter coils and is for the purpose of determining the direction of the field in the small coil system. An idea of the positions and appearance of the coils in the instrument—called a radiogoniometer—can be gathered from Fig. 32. We have here two such frame aerials supported in a vertical plane and arranged so as to be exactly at right angles to one another and symmetrical about a common vertical axis. The two aerials are connected to the two field coils respectively in the radiogoniometer, and are tuned by means of variable condensers, which are inserted at the mid-points of the field coils, these latter being wound in two halves for this purpose as previously mentioned. The rotatable search coil is connected through suitable tuning arrangements to the detecting circuits.

Now consider what is the effect of a wireless signal incident on this system. Suppose, first of all, that the signal is arriving in the plane of the A frame; in this case no current will be induced in the B aerial because it is at right angles to the direction in which the waves are travelling (see page 24), whereas the aerial A will be in its position of maximum receiving power and will have a current induced in it. This current will produce a magnetic field along the cylindrical axis of the "*a*" field coil.

On the other hand, in the case of a signal which is incident exactly in the plane of the B aerial, a magnetic field will be produced along the axis of the "*b*" field coil.

If, however, the direction from which the wave is arriving lies somewhere between the planes of the two aerials, both aerials, and hence both field coils, will have currents induced in them, and in the neighbourhood of the search coil there will now be two magnetic fields at right angles to each other, the relative strengths of which

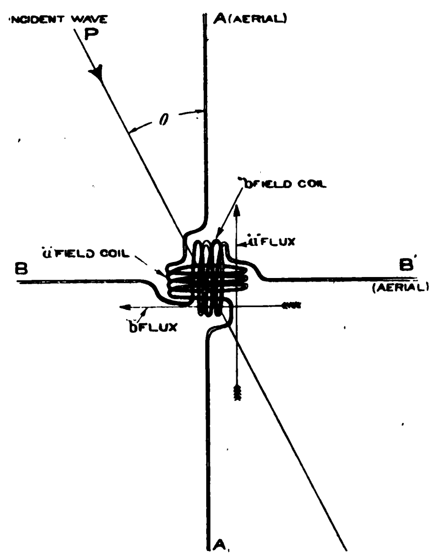


Fig. 33. *Action of Radiogoniometer.*

will depend upon which aerial most closely coincides in direction with that of the incident wave. It can, in fact, be shown that the two magnetic fields produce a resultant field which bears exactly the same space relationship to the axis of the field coils as the direction of the received signal does to the planes of the frame aerials.

Let Fig. 33 represent a plan view of the frame aerial AA′ and BB′ and the field coils *a* and *b* of the radiogoniometer, and let the arrow indicate the direction of the incident wave, making an angle θ with the frame AA′.

Now if $I_{\max}$ be the current in the aerial AA′, and hence in the field coil *a*, when the direction of the wave is in the plane of the AA′ aerial, then the current under the condition shown will be :—

$$I_a = I_{\max} \cos \theta$$

and similarly the current in the field coil "b" will be :—

$$I_b = I_{\max} \cos (90° - \theta).$$
$$= I_{\max} \sin \theta.$$

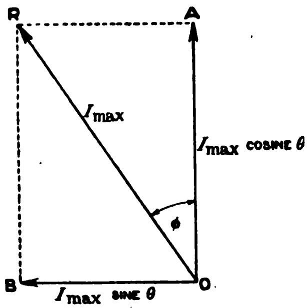


Fig. 34.
Theory of Radiogoniometer.

Since the two field coils are at right angles, the magnitude of the resultant flux may be found by a simple rectangular parallelogram of forces, and in Fig. 34 OA is drawn proportional in direction and magnitude to the flux in the "*a*" field coil and similarly OB represents the flux in the "*b*" coil, the resultant being proportional to OR, making an angle ϕ with OA.

$$\text{But } \tan \phi = \frac{I_{\max} \sin \theta}{I_{\max} \cos \theta} = \tan \theta$$

therefore $\theta = \phi$ or the angle of incidence of the wave relative to the AA′ aerial is equal to the angle of the resultant flux relative to the "*a*" field coil.

Further, since the angle AOB is a right angle :—

$$OR = \sqrt{OA^2 + OB^2}$$

or the resultant flux is proportional to

$$I_{\max} \sqrt{\cos^2 \theta + \sin^2 \theta}$$
$$= I_{\max}.$$

so that the maximum of the signal strength is dependent solely on the intensity of the incoming wave and does not vary with the angle of incidence.

The problem remaining, then, is simply to determine the exact direction of this resulting field, and this is done by means of the rotating search coil. The E.M.F. induced in the winding of the search coil is proportional to its linkage with the magnetic field, and consequently as the search coil is rotated inside the field coils, there will be a maximum E.M.F. when the cylindrical axis of the winding lies along the direction of the resultant field (because in this position maximum possible lines thread the coil) and zero E.M.F. when its axis is at right angles to the resultant field (because now, no lines thread the coil). As the search coil is moved round, therefore, the signals in the telephone receivers are found to indicate alternate maximum and minimum signals 90° apart, just as was observed in the case of the rotating frame aerial. For the reasons given on page 26 it is preferable to use the point of minimum signals for the determination of the angular position of the resultant field. A pointer is attached to the spindle of the coil and a scale is fixed to the frame of the instrument so that the direction of this field, and thus the direction of the incident wave relative to the aerials, can be read off. In the case of a land station, the aerials are generally laid out North-South and East-West, so that the bearing of any transmitting station can at once be found. (See Bibliography for references to numerous articles on the B.-T. system).

Conditions for Accurate Working of Marconi-Bellini-Tosi System. In order to obtain the ideal disposition of magnetic fields in the radiogoniometer as above described, it is necessary that a number of conditions be fulfilled :—

(1) The currents in the aerials are, of course, alternating, and it is necessary that they should be exactly in phase. If this condition does not prevail, a rotating field is produced which is superimposed on the normal stationary field, giving impure minima.

(2) The aerials must be of equal high frequency resistance, otherwise :—(*a*) The currents which flow as a result of the signal E.M.F. will not be of the correct amplitude, and (*b*) In the case of spark signals, the damping of the aerials will be unequal, again giving bad minima.

(3) The aerials must be of equal size ; unequal aerials give displaced minima.

(4) The windings of the radiogoniometer field coils must be of equal resistance (see 2), have the same number of turns, be of the same size, and be symmetrically disposed with regard to the search coil.

(5) There must be no mutual induction or capacity between the aerial circuits.

Condition (1). Phase Relation of Aerial Currents, Balancing, etc. The first condition with which the aerial circuits must comply is that the currents in the two aerials must be in phase. When an alternating E.M.F. is applied to any circuit which possesses capacity and inductance, the alternating current which flows does not necessarily rise to its maximum value at the same time as the E.M.F., but may be out of step, so that it has its maximum either earlier or later. It can be proved that if the capacity reactance of the circuit be greater than the inductive reactance, then the current will be at its maximum earlier than the E.M.F. ; such a current is called a " leading " current. On the other hand, if the inductive reactance predominates, then the current rises to its maximum value later than the E.M.F. and is called a " lagging " current.

Now, our closed loop with its series variable condenser possesses both inductive and capacity reactance, the capacity reactance being variable by the adjustable condenser, and the smaller the condenser value the greater the reactance. Consequently, when the incident wave applies an alternating E.M.F. to the loop, we can adjust the phase of the current which will flow by varying the tuning condenser. If the condenser is a little too small for the circuit to be exactly in tune, the current will lead on the wave E.M.F. If, on the other hand, the condenser is a little too large, the current will lag behind the E.M.F. induced by the wave. Only when the circuit is precisely in tune, and inductive and capacity reactances are equal, does the current fall exactly in step with the E.M.F. It is also to be noted that a very small change of tune causes a large change in the phase of the current, so that, unless the loops are very accurately tuned to the same wavelength, condition No. (1) will not be satisfied.

This accurate tuning of the two aerials is known as "balancing." In practice, the operation is performed by

means of a small oscillatory circuit coupled very loosely to both aerial systems and excited by means of a shunted high note buzzer. The E.M.F.s induced by this buzzer in the two aerials will be in phase because they are the result of one current in the small oscillatory circuit; then, if we tune one aerial to the buzzer wavelength, and after placing the pointer of the radiogoniometer in the correct position, we adjust the other aerial condenser till the best minimum is obtained, we know that the currents are in phase. (See page 236 for practical details.)

It is to be noted that it is not necessary that the aerials should be very exactly tuned to the incoming wave; it is only essential that they should both be tuned exactly the *same* wavelength as one another. If the incoming wave is a little longer or shorter than the tune of the aerials, then the currents which flow in the two loops will lag or lead on the E.M.F.s induced by the signal—but since both aerials have been accurately tuned together by means of the buzzer, the amount of lag or lead will be the same for each aerial, consequently the two currents will remain in phase.

Conditions (2) and (3). Symmetry of Aerials. These conditions are automatically complied with in practice, since the aerial loops are made equal and symmetrical and of the same type of wire. The windings on the field coils are also identical. It is essential, however, that there should be no bad contacts in either aerial circuit, as these will introduce resistance and so impair the purity of the minimum or displace it.

Condition (4). Symmetry of Radiogoniometer. Condition No. (4) is fulfilled in the design and manufacture of the radiogoniometer. Any inequality in the size or number of turns of the field coils will upset the correct relative intensities of the magnetic fields in the instrument and so shift the minimum.

Condition (5). Mutual Inductance Between Aerial Circuits. This is a very important factor and is one of the most fruitful sources of trouble in a tuned aerial D.F. station. It is absolutely essential, if clear and crisp minima are to be obtained, that there should be no coupling whatever between the two aerial circuits. The coupling may be electrostatic, electro-magnetic or conductive. The first two types are avoided by accurate laying out of the aerials so that they are truly at right angles, and by arranging the lead in from the

aerials to the receiving apparatus, in a symmetrical manner. Conductive coupling is eliminated by providing ample insulation between the two aerials. That any such coupling is undesirable can be seen from study of the effects of a wave arriving in the plane of one aerial when coupling exists. Ideally, the wave should produce maximum current in the loop which lies in its direction of travel, and no current in the loop which is broadside on, but if the loops are coupled together the aerial which should have no current in it will have a current induced by that flowing in the other aerial. This at once upsets the working of the system and gives a bad minimum which may be displaced. (Note that the minimum is bad because the current induced in the " broadside on " loop is 90° out of phase with the inducing current in the " end on " loop. This results in a rotating field being superimposed upon the normal stationary field and so gives signals at the position of true minimum.) Details of the method of testing for and eliminating coupling between the aerials are given on page 238.

It will be as well to point out at this stage that the system of two fixed aerials combined with a radiogoniometer behaves in every way as a simple rotating frame of very large dimensions. By turning the small search coil round we are, in fact, electrically rotating such a frame, and in subsequent parts of the book, when we refer to the various properties of a " frame," the reader should understand that such remarks apply with equal force to fixed aerials and a radiogoniometer.

The Tuned Aerial Marconi - Bellini - Tosi Circuit. We are now in a position to consider the complete circuit of a simple M.-B.-T. direction finder. Fig. 35 is a diagrammatic representation of such a system in which N.S. and E.W. are the two frame aerials shown fixed in North-South and East-West directions respectively. The variable con-

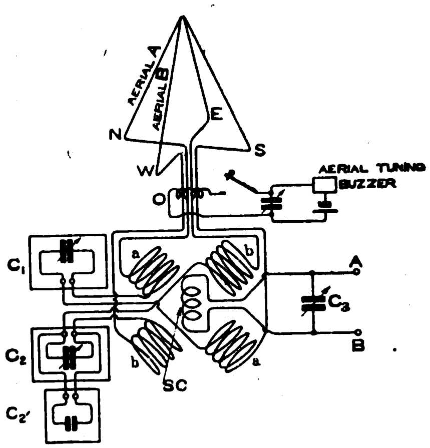


Fig. 35. *Circuit of Tuned M.-B.-T. D.F.*

densers C_1 and C_2 are connected between the split halves of the field coils *aa*, *bb*, of the radiogoniometer and a small condenser C_2' is connected in parallel with C_2. This small condenser is for the purpose of balancing the aerials, and since it is usually only about one tenth the capacity of C_2 it enables a very fine tuning of the aerial B to be obtained. This condenser is necessary, as if the condenser C_2 should be at all stiff in turning, it may be practically impossible to find a point of balance. The search coil is tuned by means of the variable condenser C_3, the terminals of which are connected to the A and B terminals of the amplifier. The tuning buzzer for balancing purposes is shown at O; it merely consists of a small wavemeter circuit placed near the leading in wires from the aerials, being excited by a dry cell and buzzer.

Such a simple circuit will work quite well as a direction finder and was, in fact, in use for a long time before the improvements to which we refer below were introduced.

The Aperiodic Aerial System. We have seen that the tuning of the two aerials of a M.-B.-T. direction finder is a very critical operation, owing to the fact that the currents must be accurately in phase. This tuning is a serious disadvantage in commercial D.F. work, because the slightest accidental change of tune of one of the aerials, such as may easily occur owing to one of the variable condensers being unintentionally moved, will upset the bearing taken on the radiogoniometer. This, and other causes, led to the development of the aperiodic aerial system.

In this arrangement the radiogoniometer is constructed so that the coupling between the field and search coil is as tight as possible, the search coil being made in the form of a cylindrical cage which fills the space enclosed by the field coils. (See Fig. 177.) If then, the aerials be connected directly to the field coils and the search coil be shunted by a variable condenser, the system as a whole may be tuned by this condenser. Fig. 36 shows an arrangement of the circuits, the

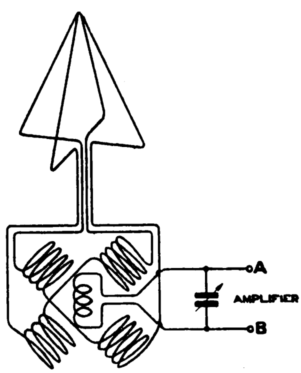


Fig. 36. Circuit of "Aperiodic" M.-B.-T. D.F.

A and B terminals of the amplifier being connected directly across the tuning condenser.

The action of the circuit can better be understood by the consideration of one aerial only. In this case Fig. 36 can be redrawn in the form indicated in Fig. 37, where F is the field coil of the radiogoniometer forming the primary winding of the transformer T and the search coil S is the secondary. The loop aerial is represented by the inductance L connected across F. C is the tuning condenser shunting S.

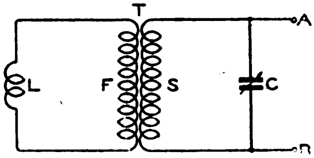


Fig. 37. Transformer Action in Aperiodic M.-B.-T. D.F.

Now it is well known, in ordinary alternating current working, that the capacities and inductances on either side of a transformer are mutually interchangeable. In fact, the circuit behaves just as if the transformer were not in existence, and provided that we allow for the ratio of transformation, we can consider the whole circuit from either the primary or secondary side. The same reasoning holds in the case we are considering. The incident wave induces an E.M.F. in the coil L (Fig. 37) and the complete circuit consists of L, the transformer (in this case the radiogoniometer) and the condenser C; consequently there will be some value of C which will bring the whole circuit into resonance with the E.M.F. induced in L. The fact that there are, in reality, two aerials and two primaries to the transformer T, need not disturb us, for we have already seen that the combination of two aerials and a radiogoniometer is in every way the electrical equivalent of a single rotating frame.

It will now be realised that no balancing is required in this system. The loops are no longer independent oscillatory circuits, and since the E.M.F.s induced by the incident wave are in phase in the loops, the currents which flow will also be in phase. This is only really true when the search coil is in such a position that no field is linked with it, but we shall return to this point later and explain it more fully. (See page 65.)

Coupling Error of Tight Coupled Radiogoniometer. On page 52 we pointed out that the direction of the magnetic flux inside the field coils of the radiogoniometer bears the same relationship to the coils as does the direction of the incoming signal to the two frame aerials connected to these coils, and

we have proved this to be the case mathematically. This is only true, however, if the two fluxes set up by the current flowing through the field coils are perfectly uniform, and this assumption was tacitly made in explaining the point. In actual fact the fields are far from uniform (62), (92).

The intensity of a magnetic flux set up by a current in any solenoid is greatest nearer the conductor forming the winding and diminishes towards the centre of the coil. This change in intensity becomes more marked when the coil is not long compared with its diameter, and consequently is very pronounced in the case of the field coils of the radiogoniometer. Now let us consider a little more closely what we are doing when we "take a bearing." It has hitherto been stated that the operation consists in turning the search coil to such a position that minimum signals are heard in the telephone receivers, thus indicating that the coil lies with its cylindrical axis at right angles to the resultant field. Since the resultant field corresponds in direction to the incident wave, the angular position of the search coil will be an accurate indication of that direction, but what we are really doing is finding by experiment a position of the search coil, such that the E.M.F.s induced in it by the current in each field coil are just equal and opposite, and owing to the non-uniformity of the two fields, this position may be different from that in the ideal homogeneous fields.

In Fig. 38 we have sketched positions of the search coil of a tightly coupled radiogoniometer. In each case the full arrow represents the direction of the resultant field at the centre of the field coils. We have imagined the field coils to have one turn only each, and the diagrams are a cross section of the windings of the radiogoniometer taken perpendicular to the axis of rotation of the search coil. In case (*a*) the resultant field lies in the plane of the 0-180 field coil, *i.e.*, there is no current in that field coil and the pointer will indicate correctly. At (*b*) the resultant field lies about 20° clockwise from the 0-180 field coil. If, however, we turn the search coil so that its plane lies along this direction, then, owing to the fact that its conductor is nearer to the 0-180 coil than to the 90-270 one, it will lie in a part of the field of the 0-180 coil which is relatively more intense than that of the 90-270 coil and consequently signals will be heard. In order to compensate for this non-uniformity of the fields, the coil must be turned to some position such as that shown in (*b*) so that

it lies further from the 0-180 coil. This gives a plus error when signals are arriving at about 20° clockwise from the North-South aerial. At (*c*) the resultant field lies at 45°

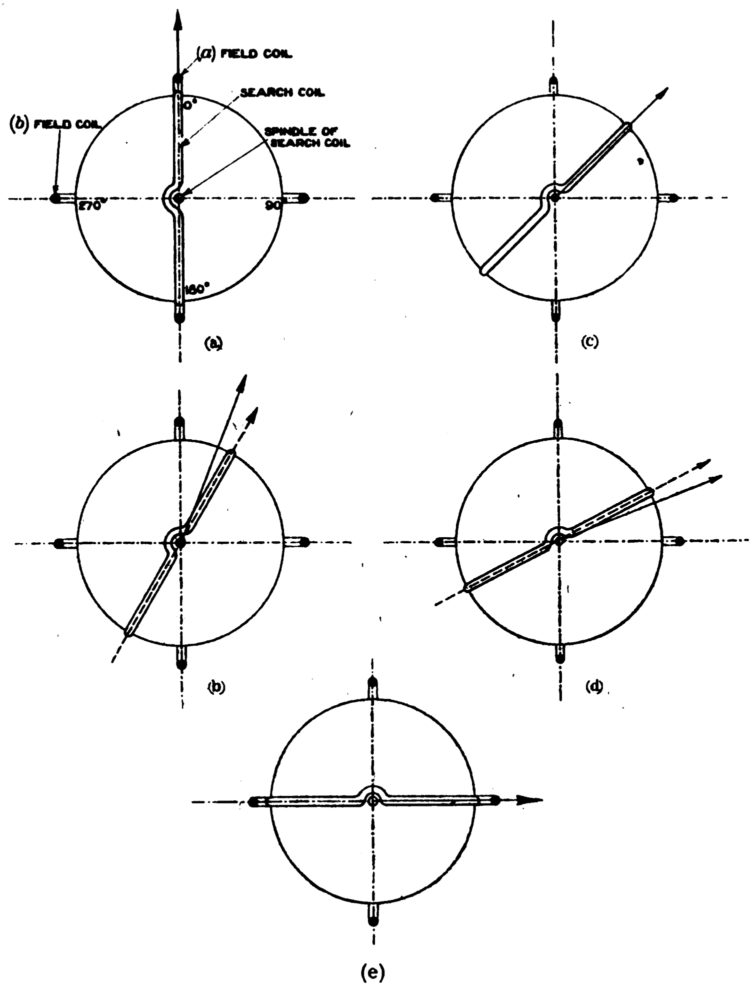


Fig. 38. *Theory of Coupling Error of Radiogoniometer.*

and in this case, since the search coil when in the plane of the resultant field is spaced equidistantly from each field coil, no error is introduced. Case (*d*) shows the resultant field about 70° from the 0-180 coil, and since the search coil is now lying in a relatively more intense portion of the field of the

90-270 coil, the actual minimum will be displaced anti-clockwise, giving a minus error. When the resultant field lies in the plane of the 90-270 coil, as in (*e*), no error ensues as in case (*a*).

This cycle of events is repeated in each quadrant and the net result is the production of an error curve such as is shown in Fig. 39. It will be seen that the error is positive in the

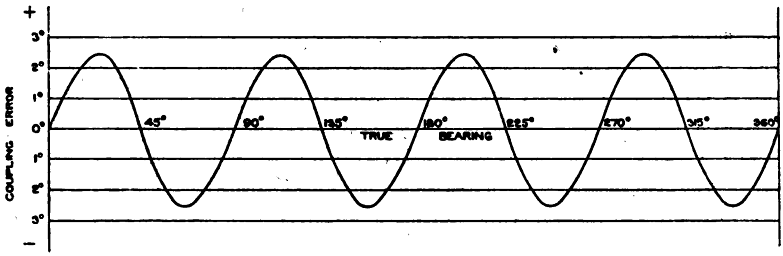


Fig. 39. *Graph of Coupling Error of Radiogoniometer.*

first octant, negative in the second, and so on. For this reason the error is sometimes known as the "**Octantal Error.**"

Correction of Coupling Error. A consideration of the error curve of Fig. 39 will show that at any two positions of the search coil which lie 45° apart, the errors are equal and are opposite in sign. If, then, two search coils are provided in the radiogoniometer, wound on the same former and connected in series, having their planes 45° apart, the resultant error should be zero. In Fig. 40 the double search coil is illustrated, and although for the position shown the axis of the compound coil is in the direction of maximum error — namely 22½° — yet, owing to the fact that each section of the search coil is lying in a position of zero error, the resultant error should also be zero.

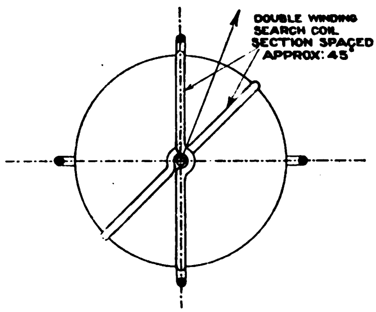


Fig. 40. *Compound Search Coil.*

The actual error curve of a radiogoniometer may be found to be not quite symmetrical. In this case the angle between the two search coil windings to give the best overall compensation may vary slightly from the 45° value. The best

angle is found by experiment for any particular design of instrument and is employed in the manufacture of the apparatus. The principle is used in most tightly coupled radiogoniometers for aperiodic aerial working, and whilst it is found in practice not to be a complete solution of the problem, the errors are reduced very considerably.

Receiving Qualities of Aperiodic Aerials. We have stated above that, allowing for the ratio of transformation of the transformer, the circuit of Fig. 37 behaves as if the transformer were non-existent, but this is only the case when the leakage field of T is very small. When a current is flowing through F, a magnetic flux is produced in the winding, and we have ensured, by constructing the radiogoniometer in such a fashion that the field and search coils are very close together, that as many lines as possible of the field shall also be linked with S. Those lines which fail to pass through S, but do pass through F, give the transformer what is known as leakage inductance. This leakage inductance causes the condenser C to have less tuning effect than it would have were the transformer not there. For the reason mentioned above, and also because the damping of the circuit is increased by the resistance of the transformer windings, the receiving power of such an aperiodic D.F. is considerably less than that of a D.F. using a loosely coupled radiogoniometer and independently tuned aerials.

Now, we showed on page 34 that the amount of distortion produced by vertical is dependent upon the receiving power of the aerial, becoming greater as the receiving power is reduced. The result is that vertical assumes much more alarming proportions in the aperiodic than in the tuned D.F., so that if we wish to keep the circuit as simple as possible, only having one condenser to adjust to tune up the system, it is essential that we should employ a shielded transformer.

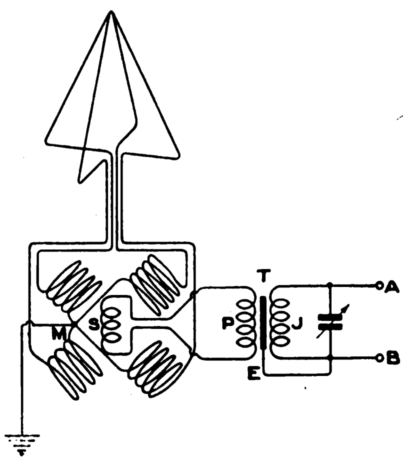


Fig. 41. Aperiodic M.-B.-T. D.F. with Shielded Transformer.

The Simple Aperiodic Aerial Circuit. Such a

direction finder is shown diagrammatically in Fig. 41, where the search coil is connected to the primary P of the shielded transformer T, the tuning condenser being shunted across the secondary J. Vertical is guarded against firstly by the application of an earth connection to the radiogoniometer field coils, and secondly by the shield E. It will be observed that in this case there is no need to bring a lead from the top of each aerial as described on page 34 and illustrated in Fig. 27. It is safe to connect the two mid-points together at M as shown, because it will be seen from the symmetry of the aerial systems that there is never any difference of potential between these points, and hence no undesirable currents will be produced as a result of making this connection.

The Aperiodic Aerial with Loose Coupled Intermediate Circuit. An important modification of the above circuit is shown in Fig. 42. In this case a coil P is inserted in series with the search coil and an adjustable condenser C_1. P is loosely coupled to a jigger secondary J, tuned by the condenser C_2, the radiogoniometer aerial circuit being tuned by means of C_1. The current flowing in the primary P as a result of the incoming signal induces a current in J *via* the loose coupling between P and J. This circuit is much more selective than that of Fig. 41, and the presence of a loosely coupled jigger renders the use of a shielded transformer unnecessary, the earthed mid-points on the aerial system being sufficient to correct the small amount of vertical present. It is essential, however, that the condenser C_1 should be accurately adjusted to bring the radiogoniometer and aerial circuits into close tune with the wave to be received. Any mistuning will reduce the receiving power of the loops and so tend to bring in vertical. It will be understood that this circuit requires more expert handling than that shown in Fig. 41, and consequently its use is generally confined to

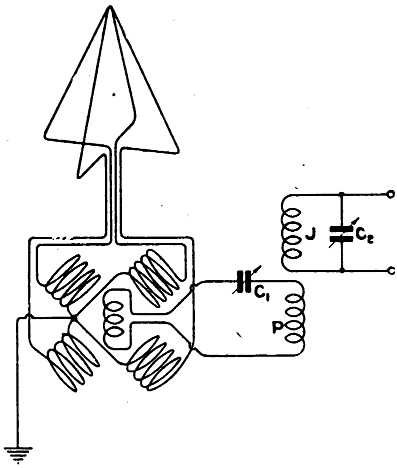


Fig. 42. *Aperiodic M.-B.-T. D.F. with Loose Coupled Jigger.*

permanent coastal or aerodrome D.F. stations where a continuous watch is kept on the D.F. and operators have the opportunity of becoming very familiar with the adjustments.

The Heart-shape Circuit with Resistance Phasing of the Open Aerial. We have already referred to the difficulty of adjusting the circuit shown in Fig. 27 owing to the critical phasing, and a satisfactory method of stabilising the phase conditions is by the method of resistance phasing as shown in Fig. 43. The principle involved in the circuit is the same as that of Fig. 27, but in this case neither the open nor the frame aerial are definitely tuned to the receiving wavelength. The open aerial has a resistance R in series, but no condenser, and the frame aerials (or rotating frame) are aperiodic. The single frame shown in the figure may represent a rotating frame or the equivalent simple frame of the Bellini-Tosi system.

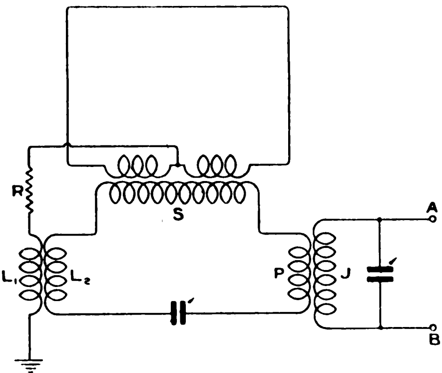


Fig. 43. Aperiodic Circuit for Heartshaped Diagram.

Now let us consider the behaviour of the system under the influence of an incoming wave. We shall suppose that the correct values for R and the various couplings have been found, and further, that the radiogoniometer search coil, or rotating frame, has been turned so that it is in the position where no signals are received by the system as a whole. In this position there must be no current in the jigger secondary and consequently no current in the intermediate circuit. Under these circumstances, let us examine the phases of the currents induced by the signals in the open and loop aerial circuits.

As previously explained, the E.M.F. in the loop will lag 90° on the flux in the incident wave ; and since the impedance of the loop circuit is almost wholly inductive, the current which flows as a result of this E.M.F. will lag roughly 90° behind the E.M.F. itself. The nett result of these two lagging shifts of phase is to make the current in the loop aerial 180°

out of phase with the flux in the wave, as shown in the vector diagram of Fig. 44, in which the dotted line represents the direction of the vector flux in the wave.

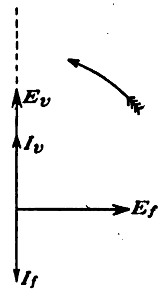


Fig. 44. *Theory of Aperiodic Circuit for Heart-shaped Diagram.*

In the case of the open aerial, the induced E.M.F. is in phase with the flux in the wave (see page 17), and if we make the resistance R so large that it completely swamps the capacity and inductive reactance of the aerial, the current which flows will be in phase with the E.M.F. (see any text-book on alternating currents). Consequently the current in the open aerial is *in phase* with the flux in the wave.

We saw above, however, that the current in the frame was 180° out of phase with the flux in the wave, so that the currents in the two aerials are also 180° out of phase. This is the phase relationship which we require for balancing the two currents, as was explained on page 44 and we are thus able to get a heart-shaped diagram.

The above relation between the phases *only holds so long as there is no current flowing in the intermediate circuit* L_2, S, P. If any current is flowing in this circuit it will react back to the aerials and so displace the phases of the currents in them. It will now be understood why we assumed the position of the search coil to be such that the incoming signal produced no current in the intermediate circuit; it was in order that the phases of the currents in the aerials could be legitimately considered independently. This shift of phases due to the intermediate circuit current is of no importance practically, since we are mainly concerned with getting a definite minimum, and there is no need to worry about the fact that the rest of the polar curve of the system does not exactly follow our theoretical heart-shaped diagram.

Completely Aperiodic Heart-shape Circuit. The above-mentioned circuit may be considerably simplified by making it completely aperiodic and employing a shielded transformer, as shown in Fig. 45, in place of the loose coupled jigger. Owing to its simplicity, this circuit is particularly suitable for ship and aircraft work. The circuit is exactly the same as that of the simple aperiodic aerial system (Fig. 41) with the exception that the transformer is provided with a third

winding in order to combine, in the detector circuit, the E.M.F.s induced by the currents in the vertical aerial and the search coil circuit. The resistance included in the circuit of the tertiary winding performs the double function of adjusting the phase and also the amplitude of the current. Its value is so chosen when designing the circuits that the best minimum possible is obtained over the whole range of wavelength covered by the transformer and its tuning condenser, although only at one wavelength is there a complete zero balance of signals.

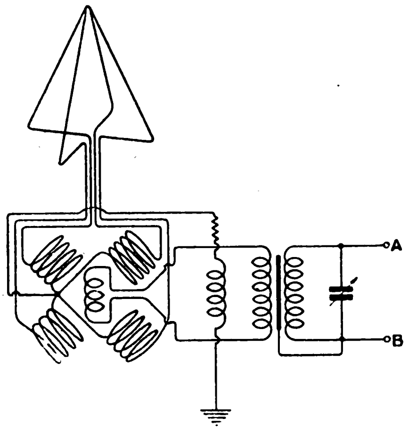


Fig. 45. Simplified Circuit for Heart-shaped Diagram as "Sense" Indicator.

Aerial Current Phase Relations in Loose Coupled, Aperiodic Aerial, Heart-shape Circuit. At this point we will examine the phase relations in the loop and open aerials of Fig. 43 a little more closely. In the explanation given on page 64 we stated that the current in the loop aerial lags 90° behind the E.M.F. induced by the incident wave on account of the predominance of inductive reactance. This is not strictly true, because the aerial and radiogoniometer field coils possess resistance, and the effect of this resistance is to make the angle of lag a little less than 90° (see Fig. 46). Let us assume that the angle of lag is actually 87°. This will mean that the current I_f in the loop aerial will lag $(87°+90°) = 177°$ on the flux in the wave, and hence, if the phase difference between this current and the current I_v in the open aerial is to be 180°, then I_v must lag by $177°-180° = -3°$, or, in other words, must *lead* by 3°. On page 54 we explained that the current leads on the E.M.F., when the tune of the aerial is a little shorter than that of the received

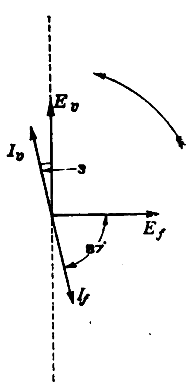


Fig. 46. Extended Theory of Aperiodic Circuit for Heart-shaped Diagram.

wave, and the inductance L_1, Fig. 43, is therefore made large enough to tune the open aerial to a longer wave than that of the incoming signal, and a series of tappings are provided in order that we may select the number of turns of L_1, which gives the best minimum. This adjustment of the inductance is comparatively coarse, owing to the presence of the resistance R. On page 243 we give some notes on the adjustment of the apparatus of this circuit in order to obtain an accurate heart-shape balance for the purposes of duplex working, "X" stopping, etc.

Such accurate adjustments of the circuits are quite unnecessary for ordinary D.F. work. The actual direction of the transmitting station is taken on a plain figure of eight circuit, then switching arrangements are provided for connecting the vertical aerial circuit and the two minima are re-examined in order to determine which one represents the true bearing of the transmitting station.

It is preferable, at any rate during the daytime, always to take bearings on the plain D.F., because :—

(1) The minimum of the figure eight diagram is much sharper than that of the heart-shape.

(2) The necessity of accurate balancing and possibility of accidental error is avoided.

Radiogoniometer for Sense Determination. Referring again to Fig. 24, which shows the composition of the heart-shape diagram by the two polar curves of a loop and vertical aerial, it will be noted that the minimum of the heart-shape is at right angles to the minima of the plain D.F. All radiogoniometers which are used for the double function of direction finding and sense determination are therefore provided with two pointers, at right angles. One pointer moves close to the scale and is engraved with a fine line for the accurate reading of bearings on the divided circle ; whereas the other is shorter and has no definite index, being used merely for examining the two minima observed by the plain D.F., in order to decide upon the sense to be assigned to the direction of the transmitting station. An illustration of such a radiogoniometer is given in Fig. 190.

CHAPTER 3.

VALVE AMPLIFIERS AND DETECTORS.

The introduction of the three-electrode valve amplifier has, to all intents and purposes, raised the direction finder from the plane of an interesting laboratory experiment to a commercial proposition. We pointed out in Chapter 2 that the receiving power of a frame aerial is very small as compared with the elevated open wire. This fact, of course, resulted in the range of the direction finder being very much less than that of the open aerial receiver when working with other ship and coast stations. It is now possible, with the aid of the three-electrode valve, to obtain any range desired by the use of sufficient amplification.

The Crystal as a Rectifier. Let us first consider briefly the action of a crystal detector in receiving a wireless signal. In Fig. 47 is shown a simple oscillatory circuit consisting of an inductance J, shunted by a variable condenser C_1. By suitably designing the coil J in relation to the range of capacity provided by the variable condenser C_1, we can make the circuit resonate to any desired series of wavelengths over the full variation of C_1. We will suppose that this is the last oscillatory circuit of our direction finder system. The incoming signal then, either by a loose coupling or by a transformer, induces an E.M.F. in the coil J. Now if the condenser C_1 is correctly adjusted (*i.e.*, if the circuit is "tuned up") an oscillatory current will build up in the inductance J, and at the same time there will be produced an alternating potential difference between the terminals A and B of the condenser C_1. The problem, then, is to render this P.D. in some way appreciable to our senses; this is usually accomplished by converting the energy which it represents into sound waves which can be detected by ear.

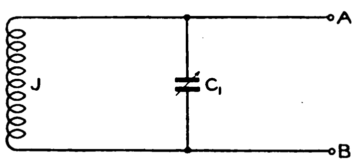


Fig. 47. *Oscillatory Circuit.*

A pair of telephones is the apparatus employed for effecting this conversion, but it is not possible to connect the telephones across the terminals A B and get a sound from the above-

mentioned PD for, apart from all other considerations, the frequency of the oscillations of all ordinary wavelengths, is far above the limit of audibility. For example, an incoming signal of 300 metres wavelength will induce a P.D. between A and B, which fluctuates at a rate of one million cycles per second. Now the ear cannot hear notes having a frequency greater than about 20,000, consequently, even if the telephone diaphragm were able to vibrate at the impossible frequency of one million per second, the note produced would be quite inaudible.

A spark or I.C.W. transmitter emits, as we have seen (page 15), a series of trains of oscillations succeeding one another at audio frequency. Now the P.D. across AB only exists for about the same time as each train of oscillations persists; consequently, if we by some means rectify the current through the telephones, due to the alternating E.M.F., a click will be heard corresponding to each train. Certain mineral substances possess the property of rectification in that they will allow a current to flow through them in one given direction. Carborundum is an example of such a rectifier, and so if we include a crystal of carborundum between the terminal A and one terminal of the telephones, as shown in Fig. 48, a direct current will flow through them each time that an alternating P.D. exists between A and B; *i.e.*, each time a wave train leaves the transmitting station. Since the transmitter is arranged to spark or interrupt the wave train at a musical frequency, a corresponding note is heard in the receiving telephones. (See further reference to this subject, page 88.)

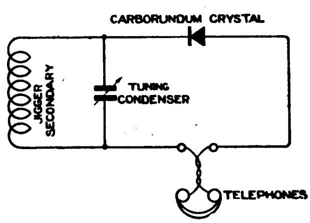


Fig. 48. *Oscillatory Circuit with Rectifier.*

Let us examine a little more closely the rectifying properties of such a crystal. The primary fact is that if an E.M.F. be applied to the crystal in a certain direction, a current flows, whilst a similar E.M.F. in the reverse direction results in no current. The current flowing through the crystal for various E.M.F.s can be conveniently represented by means of a curve, called the characteristic of the crystal. Such a curve is shown in Fig. 49.

In this curve we have called positive that direction of the current for which the crystal possesses considerable conductivity, *i.e.*, towards the right-hand side of our curve. In the diagram, positive voltages are measured off from zero along the horizontal axis towards the right, negative being from zero to the left. Similarly, positive currents are indicated upwards on the vertical axis and negative downwards.

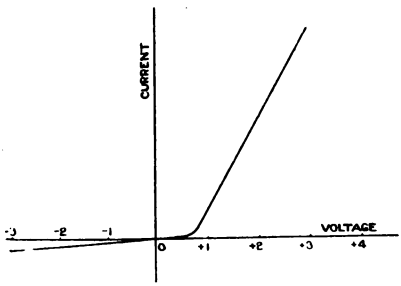


Fig. 49. *Characteristic Curve of Carborundum Crystal.*

The first thing to observe is that no current, or almost no current, flows through the crystal for all negative voltages. On the other hand, when the positive voltage exceeds about $\frac{2}{3}$ volt, a definite current flows, the intensity of which increases as the P.D. across the crystal is raised. If, then, such a crystal be connected across the jigger secondary tuning condenser as shown in Fig. 48, it can be seen that when the alternating P.D. produced by the incoming signal across the tuning condenser exceeds $\frac{2}{3}$ volt, then a pulsating direct current will flow through the telephones. The mean value of this current determines the strength of the signal heard, and hence, when a carborundum crystal is used in the above simple manner, any signal which fails to give at least $\frac{2}{3}$ volt across the jigger tuning condenser will be inaudible.

This lack of sensitiveness is overcome by the application of a constant positive voltage to the crystal of such a value that it is just on the point of becoming conductive. In the case of the crystal having the characteristic curve shown in Fig. 49, this occurs at about $\frac{2}{3}$ of a volt. Now when the oscillatory voltage across the condenser of Fig. 48 due to a signal appears, the positive half of each cycle will be added to the steady voltage and the negative half will be subtracted from it, so that if we suppose the signal to give an alternating P.D. of $\frac{1}{3}$ volt, then the voltage applied to the crystal will vary between $\frac{1}{3}$ and 1 volt as long as the oscillation persists. An examination of Fig. 49 will show that practically no current flows when $\frac{1}{3}$ of a volt is applied, whereas quite a large current results from 1 volt. We are therefore getting rectification as before, only now the oscillatory P.D. required to give a

rectified current is much smaller than in the case of the crystal without any applied steady voltage. The arrangement employed now becomes that of Fig. 50, where a potentiometer is shown in the telephone circuit. This potentiometer allows of a smooth adjustment of the steady voltage being made so that the best value may be quickly and accurately found.

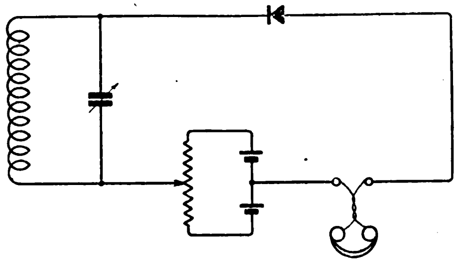


Fig. 50. *Circuit of Fig.* 48 *with addition of Potentiometer.*

Let us consider the effect of a very weak signal on such an arrangement. Fig. 51 is a magnified view of the bend of the crystal characteristic curve. The vertical line *a b* is the ordinate drawn through the point *s* (on the diagram *o s* represents 0.66 volt) and the length *p s* will then represent the current through the crystal. We will suppose that the signal superimposes upon the steady E.M.F. an alternating P.D. of 0.1 volt, then the least current flowing is given by *q t* and the greatest by *r u*, the respective increases and decrease of the steady current being *p n* and *r m*. Now the effective rectified current is the difference between *r m* and *p n*, and it can be seen from the figure that these two lines are very nearly of equal length, and consequently the rectified current is very small. In the case previously considered, nearly all the current flowing through the crystal was rectified current, on account of the fact that there was practically no current flowing during the negative half of the alternating P.D. due to the signal. When, however, the signal is weak, the negative pulses

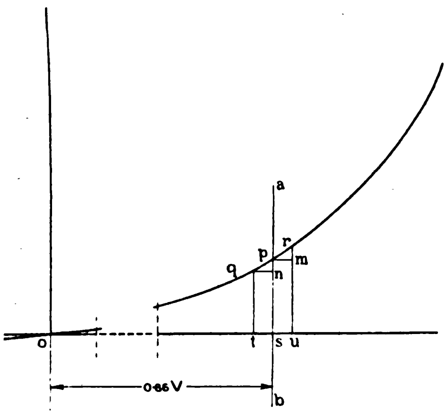


Fig. 51. *Theory of Rectification by Curvature of Characteristic.*

become of almost equal amplitude to the positive, and consequently the efficiency of rectification becomes much reduced. We thus see that a crystal rectifier is much less sensitive to a weak signal than to a strong one. This point is very important and we shall return to it later.

The Thermionic Valve. It has been found that when a fine metallic wire is heated, it emits from its surface particles of negative electricity. These tiny electric charges are much smaller than the elementary atoms and molecules which go to build up ordinary matter (solid, liquid or gas). If, then, a metal plate be placed near to the wire and a battery be connected so that the plate is connected to the positive terminal and the heated wire to the negative, the negative charges (or electrons) emitted from the wire will be attracted by the positively charged plate, and the result will be that a current will flow in the battery circuit. It should be noted that, although the electrons pass from the filament to the plate, the direction of the resulting current will be, according to our arbitrary conventions, from the positive terminal of the battery to the plate, then across the space to the heated wire, and so on to the negative terminal of the battery.

The current observed under the above conditions will be very small indeed. The large number of air molecules, which are big in size compared with the electrons, between the wire and plate, act as an effective block to the passage of the negative particles. The air molecules are all in a state of rapid motion, and the operation of getting an electron from the wire to the plate may be likened to attempting to shoot a pea from one side to the other of the Albert Hall, if the building were completely filled with footballs, all in a violent state of agitation, bouncing off each other and off the walls. For this reason, in order to get a measurable current across the space, it is necessary to enclose the wire and the plate in a vessel from which all, or nearly all, the air has been removed. This is accomplished by making the wire in the form of a lamp filament and sealing it and the plate, or other electrodes, in a glass vessel which is thoroughly exhausted. The filament can then be heated to a high temperature by passing a current through it, and since the dense crowd of air molecules is no longer present, comparatively large currents can flow across the exhausted space. Such an arrangement is known as a Fleming valve, " valve " being a generic term for all such devices, independent of the number of electrodes,

depending for their action on the emission of electricity from a hot wire in vacuo.

The Valve as a Rectifier. It was stated above that the electrons are negatively charged particles; since this is the case, they will be attracted by the plate when it is positively charged. If, therefore, we apply an oscillatory P.D. between the plate and filament, a current will flow through the valve whenever the plate is positive, whereas no current will flow when it is negative to the filament. This constitutes rectification, and the action is precisely similar in effect to that of the carborundum crystal previously considered, and consequently it may be used in a like manner for the reception of wireless signals. The characteristic curve is also very similar, as will be seen from Fig. 52, and the same considerations as to inefficiency of rectification of weak signals also apply. The main difference lies in the fact that no matter how large a reverse P.D. exists between filament and plate, no negative current flows, whereas in the case of the crystal there is a small negative current when the E.M.F. is reversed.

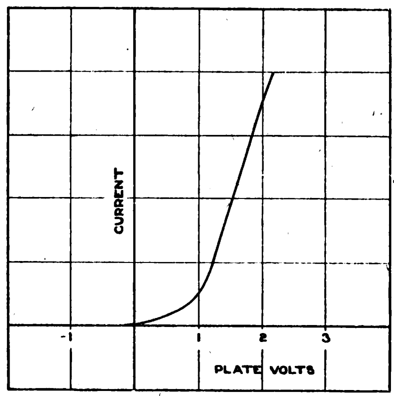


Fig. 52. *Charactertistic Curve of Fleming Valve.*

A suitable circuit is shown in Fig. 53 (the aerial and intermediate circuits having been omitted as we are not concerned with them at the moment and they have been described in Chapter 2). It will be noticed that a potentiometer is included for the purpose of adjusting the steady potential of the plate, so that the oscillatory P.D. due to the signal is applied to the

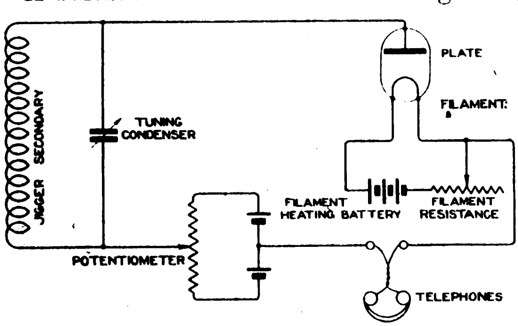


Fig. 53. *Circuit of Fleming Valve Rectifier.*

valve at the sharpest part of the bend in the characteristic curve. The bend occurs where the plate is just a little positive to the most negative part of the filament (there is, of course, a drop in potential along the filament due to the heating current), so that a separate potentiometer battery is not really needed, and all the adjustment required can be obtained by connecting the potentiometer winding across the heating battery. Also, if the telephones are inserted directly in the plate-filament circuit, they must be of high resistance. Since low resistance telephones are much more robust, it is more general practice to use them, in conjunction with a suitable transformer, in preference to high resistance telephones alone.

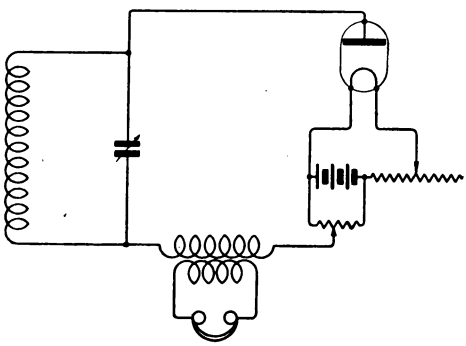


Fig. 54. Use of Common Battery for Heating Filaments and Operating Potentiometer

A diagram of a practical two-electrode valve receiving circuit therefore takes the form shown in Fig. 54. Such an arrangement is one of the most reliable receivers it is possible to have. The chief defect of the crystal detector is their liability to erratic failure, owing to the fact that the rectifying properties of the minerals are usually confined to small points on the surface of the crystal; if the contact is accidentally moved, the signals vanish. Carborundum is much the most stable in this respect and consequently is used in nearly all commercial crystal receivers.

The Three-Electrode Valve. We have seen above that when the plate of a valve is maintained at a positive potential with respect to the filament, a current will flow across the exhausted space owing to the stream of electrons from the hot wire. Now it has been found that if a metal mesh or grid be interposed between the plate and the filament, then the intensity of the electron current can be varied by varying the potential of the grid with respect to the filament. This is the basic principle of all three-electrode valve amplifiers.

Since the plate current is dependent on the grid potential, we can plot a characteristic curve of the valve which will show how the current in the grid and plate circuits vary with

the P.D. between the filament and grid. A suitable arrangement for obtaining the necessary data for plotting these curves is shown in Fig. 55, which is self explanatory. The potentiometer is arranged to allow of the grid potential being made either positive or negative to the negative end of the filament. The ammeters A_1 and A_2 are for measuring the grid and plate currents simultaneously, as the potentiometer is varied, the P.D. between the negative end of the filament and the grid for different potentiometer adjustments being measured by the voltmeter V.

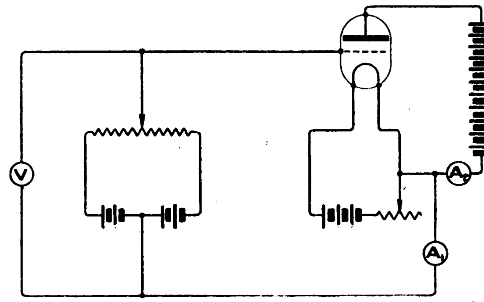


Fig. 55. Circuit for obtaining Characteristic Curves of 3-Electrode Valves.

The general shape of the characteristic curve is indicated in Fig. 56. We have plotted grid volts along the horizontal axis and plate and grid currents on the vertical axis. The curve P is the characteristic of the valve plate current and it will be seen that in the neighbourhood of the point X, when there is about zero P.D. between grid and filament, the curve is steepest. This means that at this point we are getting the maximum control of the plate current by grid potential. To the left of the point Y, the curve is coincident with the horizontal zero axis, indicating that if the negative potential of the grid is greater than about one volt, the plate current ceases to flow (the plate

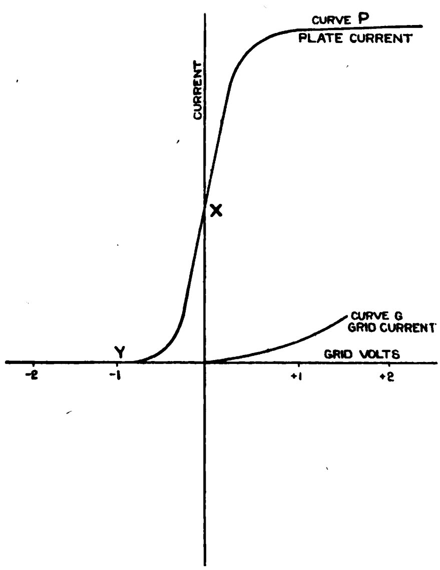


Fig. 56. Characteristic Curve of 3-Electrode Valve.

current can, of course, never reverse in direction). The bend of the curve is similar to that of a crystal, and a type of rectification can be obtained on this knee (see page 81). The grid characteristic G is comparatively flat, but it is very important to notice that *no grid current* flows until the characteristic P has passed its rectifying and steepest points.

In Fig. 57 is shown the effect of different plate potentials on the above characteristic curves. These curves are a reproduction of the actual characteristics of a Marconi V.24 valve. The steepness of the plate characteristic is not greatly affected by the plate potential, but the curve as a whole is displaced towards the left of the diagram as the positive potential of the plate is increased. The grid characteristic is practically unaltered.

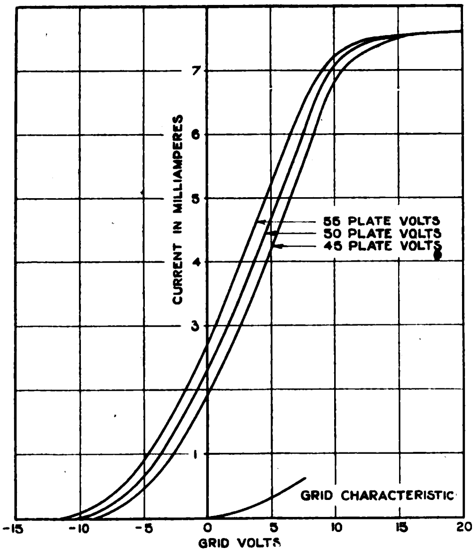


Fig. 57. Grid Volt—Plate Current Characteristics of Marconi V-24 Valve.

Now let us consider the reasons for the above existing relations between the characteristic curves of the valve. In the case of a simple two-electrode valve, as soon as a potential is applied to the plate a system of lines of electric force is set up between the plate and filament. The electrons released from the surface of the hot wire move along these wires and constitute the observed current through the exhausted space. The greater the electric stress along these lines (*i.e.*, the greater the P.D. between plate and filament), the higher will be the speed of the electrons. An increase of speed means that a larger number impinge on the plate per second, and since each carries a definite charge, a bigger current results. In this manner we get an increase in current as the P.D. across the space is increased *so long as the plate is positive.* When the plate is negative, the direction of the lines of electric

force is reversed, and since the negatively charged electrons always move towards the end of the lines terminating on the positive body, they tend to return to the filament as soon as released ; consequently no current flows. A reference to Fig. 52 will show that this explanation fits the characteristic curve there shown, there being no current for all negative voltages of the plate, and the current increasing in value as the positive potential of the plate rises.

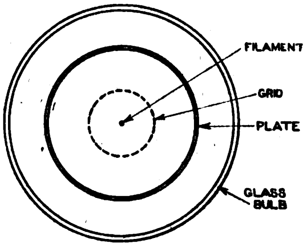


Fig. 58. *Section of 3-Electrode Valve.*

Fig. 58 is a section of a valve having a straight filament and cylindrical grid and plate surrounding it, and Fig. 59 is an illustration of a Marconi V-24 valve. If, then, a certain positive potential be applied between the plate and filament (say 30 volts), and if the grid be maintained at a steady potential (say −2 volts), the state of affairs will be somewhat as follows.

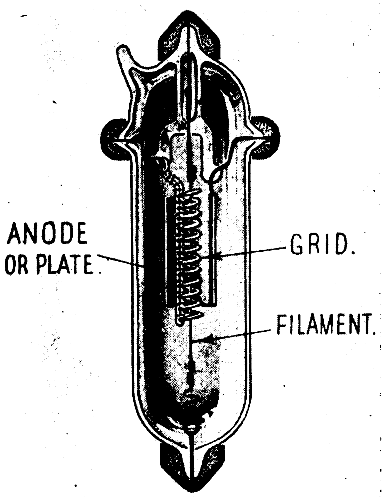


Fig. 59. *Marconi V-24 Valve.*

A field of electric force will extend from the plate towards the filament ; this field will chiefly terminate on the grid (which is 32 volts negative to the plate), but a certain number of lines will leak through the spaces in the mesh and so will reach the filament. Consequently a weak electric field exists in the space between the grid and filament *due to the positive potential of the plate.* Now if this field is weak enough, or, in other words, if the mesh of the grid is close enough, the negative potential of −2 volts which we have impressed on the grid will be sufficient to create a field in the inner space of greater intensity *and in the opposite direction.* Conse-

quently the resultant grid-filament space field is reversed and no electrons will leave the filament. In this case there can be no current in the plate circuit. As the potential of the grid is gradually made more positive, a point is reached where the field in the inner space becomes just zero and then changes in direction, and as soon as this occurs, the released electrons begin to move towards the grid, pass through its holes, and move rapidly to the plate, thus giving rise to a plate current. This plate current begins to flow whilst the grid is still at a negative potential; it is only necessary for the negative field due to the grid to be of less intensity than the positive one due to the plate. As the grid is gradually made more positive the intensity of the field in the inner space increases and the plate current rises. We thus see that a perfect control of the plate current can be obtained by means of the adjustment of the grid potential.

If the potential of the plate be increased, the intensity of the leakage field in the space between the grid and filament is increased, and therefore the grid must be more negative to reduce the field to zero and stop any electron flow. In general, to give any specified current, the higher the plate potential then the more negative the grid must be. This explains the set of characteristic curves illustrated in Fig. 57, where it will be noticed that each successive curve taken at increasing plate potentials is shifted bodily towards the left or negative side of the diagram.

Opening the mesh of the grid, *i.e.*, making the holes larger, whilst keeping the plate-filament P.D. constant, has a somewhat similar effect, because the intensity of the leakage field is increased. In this case the constants of the valve are altered and the shape of the curves is changed. We do not propose to enter into a discussion of this, however, as it belongs to the theory of valve design and is unnecessary to our purpose here.

Saturation. Referring to Fig. 57 again, it will be noticed that the curves all bend over at a certain current value, and thereafter are to all intents and purposes horizontal. This means that a limiting current value is reached at some definite positive potential of the grid, and that any further increase in the grid potential produces no corresponding rise in plate current. Now, under a certain set of physical conditions (state of surface of filament, exhaustion of vessel, temperature, etc.), a heated metal surface emits a certain number of electrons

per second. The function of the positively charged plate is to cause the electrons to move away from the filament. Consequently, when the intensity of the electric field is such that all the electrons are removed immediately they are liberated, it is clear that any further increase in the field will not result in a greater current, which has reached its limiting value. This "saturation" property is very important in practice in connection with jamming and atmospherics, and we shall deal with its application later (see page 80). The filament temperature is the controlling factor in the adjustment of the saturation current of any particular valve; the duller the filament, the smaller the saturation current.

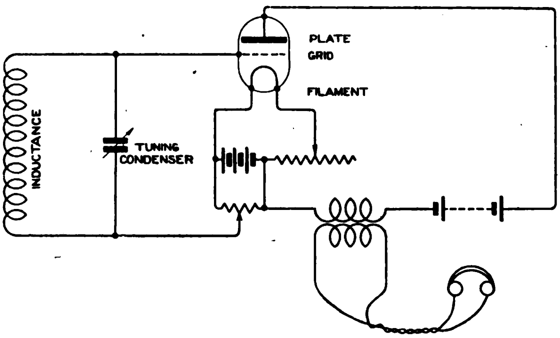


Fig. 60. *The* 3-*Electrode Valve as a Rectifier.*

The Three-Electrode Valve as a Rectifier. Let us consider the circuit shown in Fig. 60, in which case we have an oscillating circuit tuned by means of a variable condenser, connected in the grid-filament circuit of the valve. The potentiometer is shown as connected across the filament lighting battery, and if the series resistance for adjusting filament temperature be connected in the lead from the negative pole to the filament, we are sure of being able to reduce the grid potential to values lower than the most negative end of the filament. A telephone transformer and battery of suitable E.M.F. are connected in the plate circuit.

By sliding the potentiometer to the correct position, we can adjust the grid potential so that it is at the point on the characteristic curve where the plate current just begins to flow. Then when the incoming signal produces an alternating P.D. across the terminals of the tuning condenser, the grid will vary in potential as the P.D. varies. During the half cycles when the grid is more positive, an increased current will flow in the

plate circuit, and when the grid is more negative, the small initial steady current will be reduced to zero. The nett result is that during the existence of a train of oscillations, the current in the plate circuit increases in value and consequently a spark signal consisting of a series of oscillating trains succeeding each other at audible frequency, will be heard as a musical note in the telephones. It will be seen that this action is a type of rectification, and as such, its efficiency of working depends on the sharpness of the bend of the curve. We also saw, when considering the action of a crystal, that the efficiency of the rectification is dependent upon the amplitude of the received signal. Exactly the same condition applies in the case of the three-electrode valve when used as a rectifier—the efficiency falling off as the signal becomes weaker, owing to the bend being of a gentle nature and not a definite angle.

At this juncture we would point out that although a similar effect to that of a rectifier is being obtained, true rectification, such as that given by a crystal, does not occur. The signal actually causes the potential of the grid to vary, and this varying potential controls the anode current in such a manner that its mean value is increased. The P.D. induced by the signal does not directly cause a current to flow through the telephone transformer, and indeed, if the valve be so adjusted that no grid current flows as a result of the signal, no energy is absorbed from the oscillatory circuit. We thus have the important result that the signal causes the liberation of energy in the plate circuit without actually giving up any energy itself—or, in other words, the valve applies no additional damping to the receiving circuits. This will increase the strength of the received signal because a greater number of oscillations can take place as a result of each wave train, and therefore the received signals are stronger than in the case of a crystal which does apply a definite damping.

Elimination of Interference by Saturation of Rectifier. When the three-electrode valve is used as a rectifier, it is usually operated on that portion of the curve which lies on either side of the lower bend P, Fig. 61, the property of rectification being involved in the change of slope of the curve at any point. The maximum strength of signal which the valve is capable of rectifying completely, depends upon the position of the saturation bend S, relative to the arc of the curve over which the rectifying operation is being performed.

This maximum is reached when the variations in grid potential, owing to the incoming signal, are such that the plate current reaches saturation at one end of its swing.

Suppose that medium strength signals are being received and are represented in Fig. 61 by the oscillations A and that the signals are being rectified over the arc Q Q′, the ordinate *q* Q being a measure of the rectified current. A loud jamming station B is now heard, the rectified current from which signals is equal to the ordinate *r* R, rendering, we will suppose, the first signal unreadable. Now, by reducing the filament current of the valve, the saturation value S can be lowered until the ordinate *r* R″ is equal to the ordinate *q* Q″, and the jamming signals are hence of the same strength as the first signals. The interference caused by atmospherics may often be reduced in the same way. No advantage is gained in reducing the filament current below this value, as both signals will be reduced in proportion.

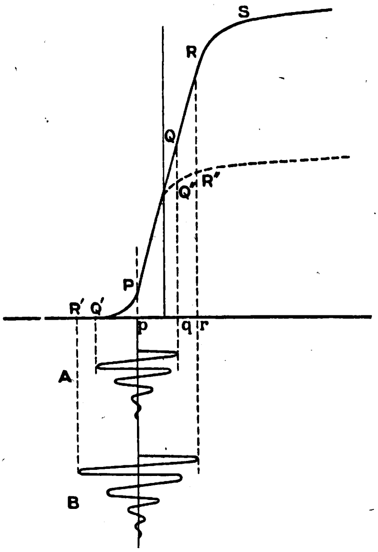


Fig. 61. *Saturation Method of Eliminating Interference.*

If, now, the signals are on different wavelengths, the problem of tuning out the jamming signal presents little difficulty, but the great feature to be noted is that, if they are on the same wavelength, it is still possible to reduce the jamming signal to negligible strength under certain circumstances.

It was mentioned above that the rectifying property of a valve is involved in the change of slope of the characteristic curve and thus there are two points at which rectification may take place, namely, on the normal rectifying bend P, Fig. 61, and also on the saturation bend S. At some place intermediate between the two rectifying points for any given signal, a point can be found at which, owing to the differential action of the two bends, there is no rectification, and hence no signals in the telephones.

Suppose, now, a weak station A is being received when it is jammed by a strong signal from a second station B, on the same wavelength, so that, having reduced the telephone signals of both stations to equal intensity by the above saturation method, the interference is still serious and cannot be eliminated by tuning. On adjusting the grid voltage by means of the potentiometer, until the voltage swing of the stronger signal is taking place over the straight portion of the curve and also both the upper and lower bends, a point can be found at which there is no rectification. Owing, however, to the fact that in any given valve the curvature of the two rectifying bends is very rarely the same, the point of zero rectification for the weaker signal A will not be the same as that for the strong signals. The result of this is that a working point can be found for the weak station A at which B is not heard, so long as one signal differs from the other in some essential way which will affect the rectifying point, such as the amplitude or damping.

In view of the fact that the three-electrode valve does not increase the damping of the circuit in which it is used as a rectifier, and also owing to its above mentioned saturation properties and its general stability, a valve rectifier is always used on modern receiving circuits. It is not proposed to deal in any greater detail with this branch of the subject; for a more systematic study, the reader must refer to treatises devoted to the subject of the three-electrode valve.

The Valve as a Magnifier. A study of the curves of Fig. 57 will show that at the steepest part of the plate characteristic curve a comparatively small change of potential causes a large variation of the plate current and also that, by choosing a suitable plate voltage, this current variation may be produced without any grid current flowing. If, then, we make the signal vary the grid potential at some frequency, we may obtain magnified fluctuations of the plate current, which will faithfully follow the variations of the grid-filament P.D. This ability of the plate current to follow variations of grid potential is practically independent of frequency, and consequently we may apply the high frequency E.M.F. of the signal to the grid, and corresponding variations of plate current will occur. This property of the valve has been experimentally confirmed up to frequencies of 300,000,000 per second (a wavelength of 600 metres corresponds to a frequency of 500,000 per second).

In Fig. 62 is shown a simple method of using the valve as a magnifier. The first oscillatory circuit has a current induced in it by the incoming signal and the consequent alternating P.D. across its tuning condenser causes corresponding fluctua-

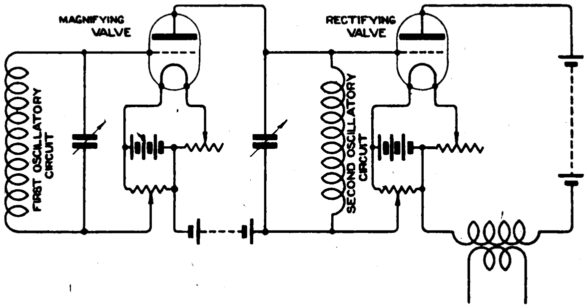


Fig. 62. *Magnification and Rectification by* 3-*Electrode Valves.*

tions of the grid potential of the magnifier valve. The steady potential of the grid of this valve is adjusted by means of the potentiometer to such a value that the characteristic is at its steepest part, and therefore corresponding pulsations of the plate current occur. A second oscillatory circuit is provided which is connected directly in the plate circuit of the magnifier valve and which is tuned to the frequency of these undulations. The result is that an oscillatory current is produced in this second circuit, which, however, is of much bigger amplitude than the original signal current in the first circuit. The way in which the undulating current induces an oscillatory current is very similar to the manner in which a shunted buzzer excites a wavemeter, only, in the case of the valve, the impulses are timed to occur just at the right instant, and hence, to induce comparatively large oscillatory currents, only very small individual impacts are required. The oscillations in the second circuit result in an alternating P.D. across its tuning condenser, which is applied to the second valve, the latter being adjusted to the bend of its characteristic and so gives a rectified current through the telephone transformer.

It is important to notice the sequence of the operations. The signal is first magnified and then rectified. By following this plan, the inefficiency of the rectifier for weak signals is countered and a P.D., which would be too weak to operate the rectifier valve direct, will do so after being magnified.

Reaction. The amplification can be further increased by the use of the principle of reaction. Let us suppose that the valve is giving an effective current magnification from the first to second circuits of 1 : 5; so that if the signal induces a current of 1 milliampere in the first oscillatory circuit, then, as a result of amplification by the valve, a high frequency current of 5 milliamperes will flow in the second circuit. Then we may, by coupling the first and second circuits together, transfer back energy at a rate represented by a reduction of the second circuit current to 4 milliamperes. This will increase the original 1 milliampere in the first circuit to, say, $1\frac{1}{2}$ milliamperes, and when this is magnified, the current in the second circuit will be $7\frac{1}{2}$ milliamperes, so that more power will now be handed back by the coupling to be in turn amplified, and so on. It might at first sight appear that this process would go on indefinitely, and once started, the circuits would maintain themselves in a state of continuous oscillations with the weakest reaction coupling. This would be so were it not for the resistance of the oscillator circuits, and depending on the closeness of the reaction coupling, we may either :—

(*a*) Simply build up the signal to a certain amplitude.

(*b*) Cause the circuits to oscillate persistently to a certain amplitude.

The limiting amplitude is determined in each case by the condition that the power supplied by the valve shall be just equal to the losses due to resistance in the circuits. An interesting case is when the reaction is of such a value that persistent oscillations just cannot take place. In this case the circuits behave as though they had no resistance whatever, and the fullest advantage of allowing the signal to build up by resonance may be obtained.

Fig. 63 is a redrawing of the circuit of Fig. 62, but with the inclusion of a reaction coil to give magnetic coupling between the grid and plate oscillatory circuits. In a practical receiving circuit of this type, the reaction coil is generally made to rotate on an axis in the plane of the winding, so that the coupling given by it may be adjusted in intensity or reversed in direction. There is only one correct direction for the coupling, for if the magnetic field of the reaction coil is in such a direction that the E.M.F. induced by it in the plate oscillatory circuit tends to stop the current flowing in it,

then instead of helping the oscillations to build up, the reaction will hinder them.

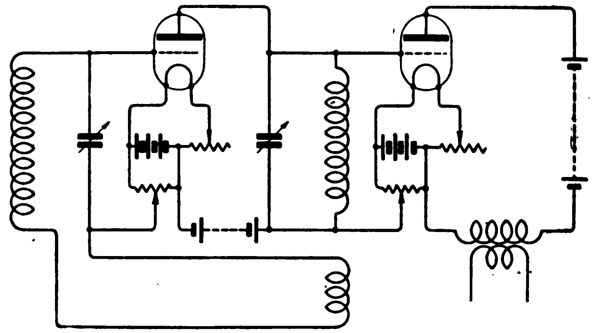


Fig. 63. *Use of Reaction.*

Heterodyne or Beat Reception of Continuous Waves. The frequency of electro-magnetic wave motion is, except when the wavelength is extremely great, beyond the range of human audibility, and it is the comparatively low frequency of the separate short wave trains of the I.C.W. and spark or damped wave systems of transmission which, after rectification, render the signals audible in the telephone receivers. In the case of continuous waves, the modern method of producing the necessary audio frequency fluctuations in the amplitude of the high frequency currents is by the production of " beats " caused by superimposing on the signal E.M.F. in the receiving circuits, a second oscillatory E.M.F. which has a slightly different frequency from that of the signal. The process may best be explained by the use of a diagram. In Fig. 64 we have shown two sets of continuous oscillations A and B, in which the A train consists of 16 complete oscillations, and the B train of 14 complete oscillations, both taking place in the same period of time as represented by the length of the base line X Y. Now, assuming that the two wave motions are in phase at the instant X, then, since their frequencies are different, they clearly cannot remain in phase. We can, however, see that since A makes 8 complete oscillations to every 7 of B, then at regular intervals corresponding to every eighth oscillation of A, the two wave motions will instantaneously come into phase again, after which the whole phase cycle will be repeated. Midway between these " in phase " instants will be instants of complete phase opposition.

These conditions may be illustrated as in Fig. 64 C, where the ordinates of the two sets of oscillations have been added algebraically at every instant, and the amplitude of the resulting wave motion is seen to be a maximum where A and B are in phase, and a minimum at the periods of phase opposition. This periodic fluctuation in the amplitude of the resulting oscillations is known as "beats," and the frequency of the "beats" is seen to correspond to the difference in the frequencies of A and B. The frequency of the "beats" can therefore be varied at will by changing either of the high frequencies.

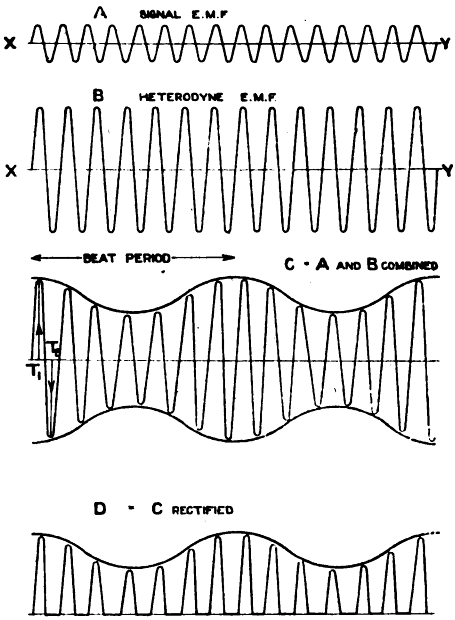


Fig. 64. *Beat Reception.*

Applying the above to the case of reception of continuous waves, suppose that the E.M.F. in a certain receiving circuit has a frequency of 100,000 cycles per second, corresponding to a wavelength of 3,000 metres, then by inducing in the receiving circuit a second alternating E.M.F. which has a frequency differing from the first by 1,000 per second—that is to say, the second frequency may be either 99,000 or 101,000—a series of beats will be produced in the resultant E.M.F. and current having a frequency of 1,000 per second.

The Heterodyne or Independent Local Oscillator. For the purpose of supplying the additional E.M.F. to produce beat reception, a small continuous wave transmitter is used locally, with arrangements for coupling it to the receiving circuits.

When the reaction coupling of the circuit of Fig. 63 reached a certain critical value, we saw that persistent oscillations

were set up and Fig. 65 shows a simple form of valve oscillatory circuit which is specially adapted for use as a local oscillation generator. The wavelength of the circuit is adjusted by means of the variable tuning air condenser, further ranges of wavelength being obtained by connecting this condenser either across the grid coil alone or across the grid and plate coils in series. A rotating coupling coil is provided which may be connected in series with a part of the receiving circuit.

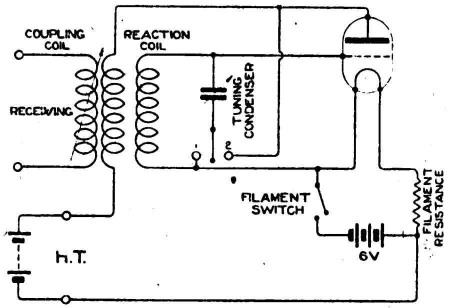


Fig. 65. Circuit of Local Oscillator.

In ordinary wireless reception there is not always any particular necessity for a special coupling coil, as the heterodyne may be coupled quite tightly enough to the receiving circuit by placing the instrument on the receiving bench and adjusting its position until the correct intensity of heterodyne E.M.F. is obtained. In direction finding, it is important that the coupling should only take place between the oscillator and the receiving circuit proper, and not on any account with the frame aerials or the radiogoniometer field coils and search coil of the B-T system. It is customary to have the heterodyne well shielded and placed at some distance from the direction finding apparatus, leads being brought from the coupling coil of the instrument to the receiving apparatus and coupled in one of the following ways :—

(1) To the jigger secondary.

(2) In series with the high tension battery.

(3) In series with the filament and grid of the rectifying valve.

The second oscillatory E.M.F. may also be obtained by causing the valve circuit of the receiver to oscillate persistently, the small change of frequency being obtained by detuning the circuit slightly until the required beat frequency is produced. This has a disadvantage on long wavelengths, owing to the fact that the detuning required to produce a beat frequency of, say, 1,000, becomes very appreciable when the frequency

of the incoming signal is itself only 50,000 or so, although with short wavelengths and corresponding high frequencies, the detuning is almost negligible. This process is sometimes called the " self heterodyne " or autodyne principle.

The self heterodyne method cannot be used with a radio-goniometer unless special precautions are taken to eliminate all trace of coupling error. Unless this is done, the slight changes in the inductance of the circuit as the search coil is rotated will give a varying interference note, which may be sufficiently serious to prevent accurate direction finding.

Sensitiveness of Heterodyne Reception. We have already seen (page 71) that the efficiency of rectification of weak signals is very low, owing to the fact that the whole operation takes place over an arc of the rectifying bend of the characteristic curve of the crystal or valve, which is a gradual curve instead of an abrupt one.

Fig. 66 shows diagrammatically the way in which the application of a heterodyne E.M.F. to a weak C.W. signal E.M.F. enables full advantage to be taken of the steep part of the characteristic for the positive pulses of the beat E.M.F., whilst it also renders the grid sufficiently negative to prevent the negative beat E.M.F. oscillations producing more than a negligible amount of current. The result is a very considerable increase in the efficiency of rectification of C.W. signals.

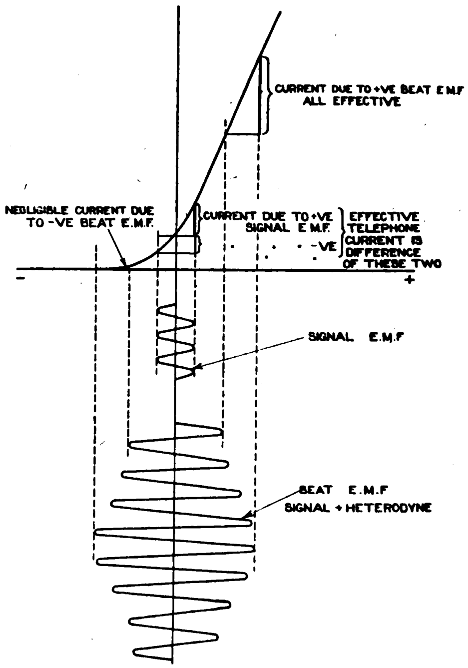


Fig. 66. *Increased Efficiency of Rectification due to Heterodyne Reception.*

Necessity for Rectification Before Note Magnification or Telephone Reception. Although beats may be produced which have a frequency of any desired value, rectification is still necessary

before the beat currents can be either received in a telephone or amplified by means of an audio frequency magnifier such as is described later in this chapter. The only frequency existing in the types of oscillations shown in Fig. 64 C is a high frequency of the same order as that of A and B. Although the amplitude of the high frequency wave motion is varying at audio frequency, still *there is no actual low frequency component present in the oscillations themselves.* Consider the effect of applying this beat current direct to a telephone receiver. Although at any instant T_1, Fig. 64 C, near the maximum amplitude, the instantaneous current might be sufficiently great to operate the diaphragm of the telephone, yet, at the next instant, T_2, and long before the diaphragm has had time to respond, the current has reversed and is tending to move it in the opposite direction with an almost equal force.

It is the general appearance of the " envelope " (that is, the line drawn through the peaks of the high frequency oscillations), which makes the beat oscillations seem to have a low frequency component, but an inspection of this envelope will show that the low frequency current (or E.M.F.) which it might be taken to represent, has at all times got an algebraic sum of zero, the amplitude of the curve in the positive direction —or above the zero line—being always opposed by an equal and opposite negative value below the line. It is only when either the upper or lower portions of the system have been completely removed by rectification, as shown in Fig. 64 D that the low frequency component becomes available for operating a telephone or the circuits of a note frequency amplifier.*

The Valve as a Note Magnifier. We have, so far, only considered the cases of using the three-electrode valve as a rectifier or as a magnifier of high frequency oscillations induced by the incoming signals in the receiving circuits. It may also be used for amplifying the relatively low frequency currents in the telephone circuit after rectification has taken place. Fig. 67 illustrates such a circuit for amplification of note frequencies in two stages. The terminals on the receiver, to which the low resistance telephone would normally be connected, are taken to the primary of the first transformer. Now we have seen that the valve operates simply by

* It is assumed that the telephones are of the polarised type which is almost universally used for wireless work. The non-polarised pattern of receiver is itself, to some extent, a rectifier.

changes of potential of the grid and that no current flows in the grid circuit. Consequently, the secondary winding of the

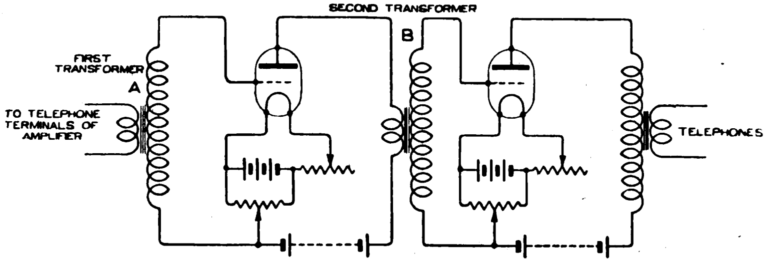


Fig. 67. *Two-Stage Note Amplifier.*

transformer is wound with a very large number of turns of fine wire in order to step up the voltage produced across the amplifier terminals by the signal as much as possible before it is applied to the first valve of the note amplifier. This long winding is connected between grid and potentiometer slider of the first valve in the usual way, the potentiometer being for adjusting the steady potential of the grid and so ensuring that the valve is operating on the steep part of the characteristic. The magnified currents in the plate circuit flow through the primary winding of the second transformer. This is also a step-up transformer, and the long secondary winding is connected across the grid and potentiometer of the second valve. The currents in the plate circuit of this last valve pass through a step-down transformer and operate a low resistance telephone.

A double stage amplifier such as this gives very strong signals in the telephones, but it must always be borne in mind that it can only be used to amplify currents which exist after rectification has taken place. If the signal voltage which acted on the rectifier is too small to give any rectified current (see page 70), then obviously no amount of note amplification can render the incoming signal audible. A note amplifier, therefore, does not effectively increase the sensitivity of the receiver (at any rate for spark signals) beyond a certain point ; at the most it can only render a low frequency current capable of being heard, which would otherwise be inaudible.

It is not necessary to use separate batteries to run the valve filaments or to supply H.T. voltages for the plate circuits. The circuit shown in Fig. 68 may be employed, in which these batteries are each common to the two valves. It

will also be noticed that the potentiometers are omitted. The valves used in note amplifiers are usually of such design that,

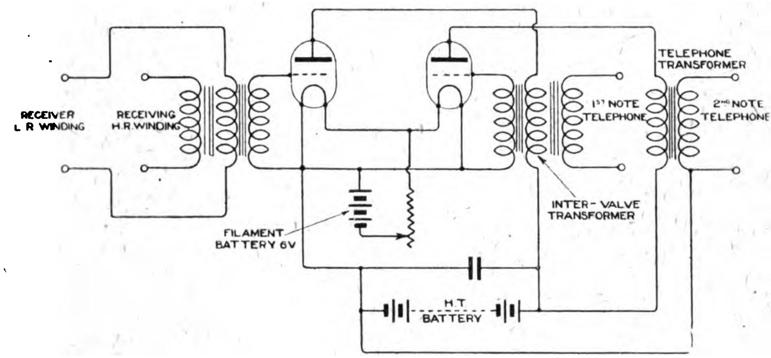


Fig. 68. *Two-Stage Note Amplifier with Common Battery.*

with normal H.T. voltage, the steepest part of the plate characteristic corresponds with a potential of the grid the same as that of the negative end of the filament.

High Frequency Cascade Amplifiers. A circuit for the amplification of high frequency currents was described on page 82 and illustrated in Fig. 62. In this case, only one stage of amplification is obtained. If we desire to magnify the signals still further, the circuit of Fig. 69 may be used.

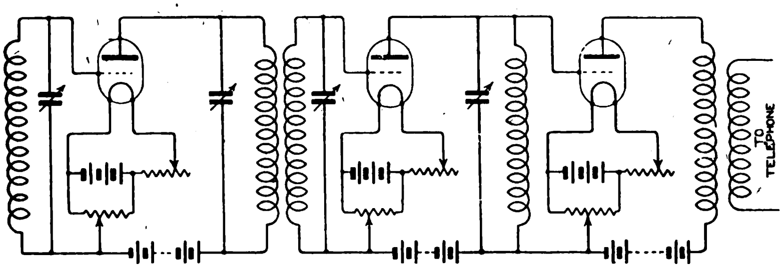


Fig. 69. *Tuned Cascade High Frequency Amplifier.*

It will be observed that instead of connecting a rectifier across the plate oscillatory circuit we have coupled another tuned circuit to it, magnified the current induced in this latter circuit by means of a second valve, rectification taking place after this second stage of high frequency magnification. Such a system is quite workable in practice though the valves have a strong tendency to maintain continuous oscillations in the circuit, which must be annulled by the use

of reaction coils. A large number of adjustments are involved in this circuit, including first of all the ordinary receiver circuits, namely, the aerial and intermediate circuits which are not shown in the figure, and then four separately tuned circuits associated with the valves. Under these circumstances the tuning up of a cascade amplifier consisting of two or more valves is very laborious, and "searching" for a station becomes an impossibility. These and other difficulties led to the development of the modern multi-stage amplifier, in which no tuning is involved.

The Pure Resistance Amplifier. Consider the case of a valve arranged as in Fig. 70. We have connected a resistance R in the plate circuit, and any current which flows from the plate battery B through the valve must also pass through the resistance. The potential of the grid is variable by means of the potentiometer P.

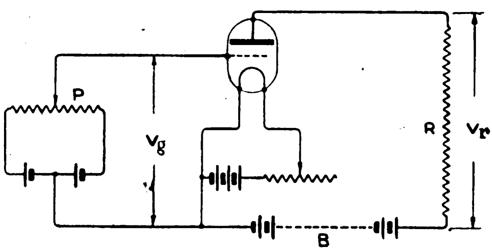


Fig. 70. *Theory of Resistance Amplifier.*

Now suppose that we start with the grid very negative with respect to the filament, no current will flow through the valve and resistance and there will be no potential drop across R, and consequently the whole voltage of B will be applied between the plate and filament. As the grid is made less negative, a point will be reached where the valve begins to conduct, and as soon as a current flows there will be a certain potential drop across R, which we will call V*r*. As the potential of the grid (V*g*) is made less negative (or more positive), the conductivity of the valve increases, and therefore the value of V *r* increases. We thus see that, within certain limits, fluctuations of potential of the grid are reproduced as fluctuations of potential across R, which are much greater than the grid variations causing them. If a given small change in grid voltage V*g* causes a certain change in resistance voltage V*r*, then the ratio $\frac{\text{change in resistance voltage}}{\text{change in grid voltage}}$ is known as the **Voltage Magnification** of the valve and circuit. It can be shown that this voltage magnification increases as R is increased, though not proportionately; rising quickly,

until for large values of resistance it becomes practically steady. The numerical value of this limiting ratio is known as the **Magnification Constant,** or, more shortly, the " m " value of any particular design of valve.

It may be observed that, in general, a valve which has a high " m " value has also a high effective resistance across the space. These points are well shown in the well-known Marconi " Q " and " V.24 " valves. The former has an " m " value of about 30 and an internal resistance of about 2 megohms; on the other hand, the V.24 valve has an " m " value of about 6 and an internal resistance of about 20,000 ohms. The " Q " valve grid is a close mesh of nickel gauze, whereas the grid of the V.24 consists of an open spiral of nickel wire.

A number of valves may be connected in cascade, each arranged as a pure resistance amplifier. It is only necessary to connect the grid and filament of each across the anode resistance of the valve preceding it in the series. Since there is a considerable P.D. across the resistances, it is necessary to adjust the various grid potentials to their correct values by means of auxiliary batteries introduced in the grid filament circuits, or by other means. It should be noted that a pure resistance cascade amplifier will magnify a steady E.M.F. impressed on the grid of the first valve, and it is unique in this respect. The circuits are, however, rather complex when set up, owing to the necessity of providing the back E.M.F. batteries for the adjustment of the potentials of all the grids, and it is therefore only used in practice when special circumstances render it imperative.

Transformer Amplifiers. In considering the pure resistance amplifier, we saw that changes in grid potential produced magnified repetitions of such changes across the resistance connected in series with the plate circuit of the valve. A little consideration will make it clear that since the grid potential is varying at a high frequency, any impedance (resistance, inductance or capacity) may be connected in the plate circuit with similar results. A condenser cannot be employed, because there is a steady current through the valve, but an inductance may be employed, and we have shown such a circuit in Fig. 71, in which the inductance L replaces the resistance of Fig. 70. A and B are the grid and filament (or potentiometer) terminals of the amplifier, and the final oscillatory circuit of the receiver is connected across them.

Let us consider the action of such an arrangement. Before the signal arrives we have adjusted the potentiometer P to such a position that the valve is working on the steepest part of its characteristic curve. When the signal produces an oscillatory potential difference across A and B, the resistance of the filament-plate space will vary synchronously with it. Now, if L has a negligible resistance, the P.D. across the valve is given (from Ohm's law) by the product of the resistance of the valve and the current through it, and since the current, owing to the presence of L, tends to remain constant, the P.D. across the plate-filament space will vary. The E.M.F. across L is equal at every instant to the difference between that of the plate battery, and that across the valve, and since the plate battery is supplying a constant E.M.F., the P.D. across L will vary in synchronism with the variations of the potential of the grid.

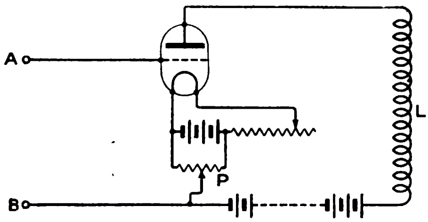


Fig. 71.—*Theory of Inductance Amplifier.*

The largest variations across L will take place when its impedance is large, but any inductive winding possesses the greatest impedance for any frequency when its natural frequency is equal to that of the applied E.M.F., and so the maximum voltage magnification will occur when L is of such a length that its natural wavelength is the same as that of the incoming signal.

Such an arrangement readily adapts itself to the construction of a multi-stage amplifier such as that shown in Fig. 72, the

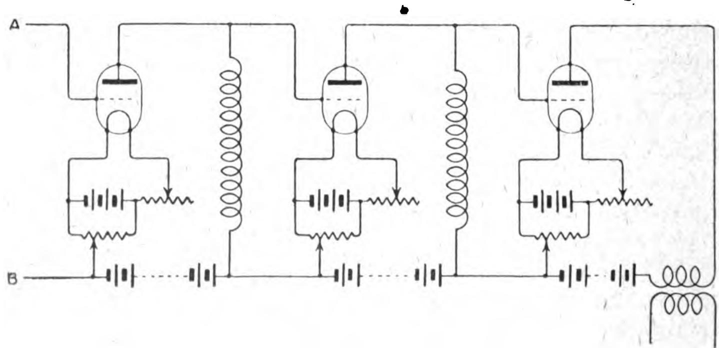


Fig. 72. *Cascade Amplifier.*

last valve being adjusted to its rectifying point. It will be seen, after a study of this figure, that it is necessary to use a separate filament battery and a separate plate battery for each valve. Any attempt to make either or both of them common will result in a short circuiting of one or the other. In order to overcome this difficulty, the modern type of transformer amplifier has been developed. In this type of amplifier each plate inductance is provided with an exactly similar secondary winding, which is connected in the grid circuit of the following valve, as shown in Fig. 73. It is

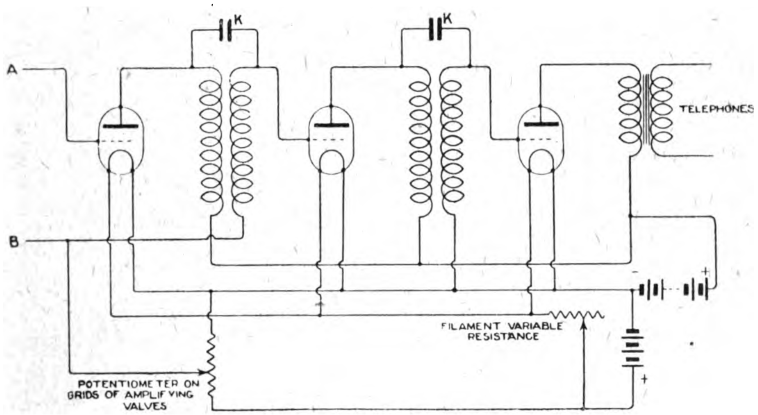


Fig. 73. Cascade Transformer Amplifier with Common Batteries.

now possible to make both the batteries common to all the valves, and the operation of the set is thereby much simplified. Small condensers (K., in Fig. 73) may be connected between the top ends of the transformer windings to help the transfer of potential variations from valve tó valve.

Characteristics of Cascade Amplifiers. We have pointed out that the transformer amplifier gives the greatest magnification when the natural wavelength of the circuits coincides with that of the received signal, and the curve of magnification is shown in Fig. 74. Now the resistance cascade amplifier is quite aperiodic, so that its characteristic curve should be a straight line parallel to the base line, but owing to the capacity of the valves themselves, a shunt circuit to the resistance is formed by the valve for currents of very high frequency, *i.e.*, short wavelength, and actually the magnification curve for such an amplifier is a line which starts from the

origin and gradually rises to a limiting value for very long wavelengths, and this is also shown in Fig. 74.

The Aperiodic Transformer Amplifier. Although very high amplifications can be obtained by means of the transformer amplifier, it has the disadvantage that the wavelength on which the maximum magnification is obtained is very sharply defined, so that it is not at all well adapted to wireless receiving circuits on which it is required to work over a range of waves, as is frequently the case in direction finding work. It is therefore usual to employ an amplifier in which the transformers are wound with high resistance wire, thus combining the effects of high magnification and wide range. This compromise results in the flattening out of the resonance peak, with a corresponding gain in magnification to other wavelengths, and by adding one or two more valves at the amplifier, a much more satisfactory resultant characteristic curve can be obtained than with either of the other methods alone. The third curve of Fig. 74 illustrates this.

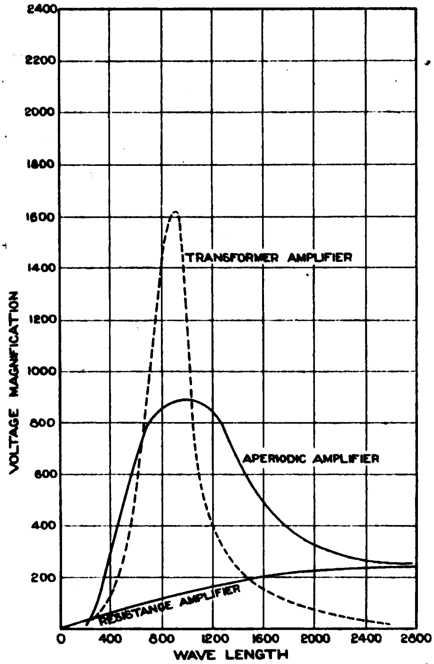


Fig. 74. Voltage Magnification Curves of Different Types of Amplifier.

Practical designs of the high and low frequency aperiodic amplifiers are shown in Figs. 198, 199 and 223, and diagrams of connections in Figs. 191 and 219.

CHAPTER 4.

MAPS.

In order to appreciate to the fullest extent the ways in which the wireless direction finder may be used as an aid to navigation in the case of a ship or aircraft, or as a simple direction or position finder in the case of a shore station, it is necessary to have a thorough acquaintance with the various types of maps which are used for the work. Furthermore, in the former case, in which the direction finder is installed on board a moving object, a knowledge of the elements of navigation is advisable, in order to make intelligent use of the apparatus.

In this chapter we shall investigate some of the ways in which the surface of the earth may be represented as a map or chart, showing in each case the uses and limitations, as applied to wireless direction finding, of the various methods.

The Earth. The dimensions of the earth and the method by which positions on its surface are located by the use of lines of "**latitude**" and "**longitude**" will be familiar to a large number of readers, but a certain amount of recapitulation will not do any harm.

The shape of the earth (Fig 75) is that of an "oblate spheroid," which corresponds closely to that of a sphere which is slightly flattened. The **North Pole** and **South Pole** are the names given to the points at the extremities of the least diameter, the

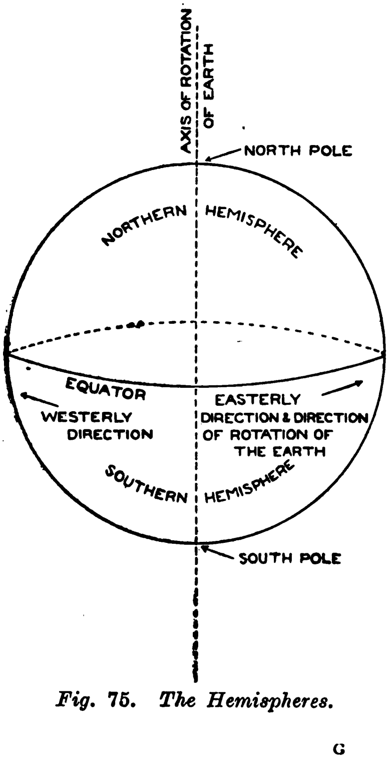


Fig. 75. The Hemispheres.

length of which is 7,900 statute miles, and this diameter is also the axis of rotation of the earth. A line round the earth mid-way between the poles, and hence at the position of maximum diameter, which is 7,926 statute miles, is called the **Equator.** For our purposes the earth may, without hesitation, be considered as a perfect sphere, the errors introduced thereby being very slight.

The lines of latitude, which are discussed in greater detail below, are usually known as **parallels of latitude** or simply "**parallels,**" and that portion of the earth which is on the same side of the Equator as the North Pole is known as the **Northern Hemisphere,** whilst the other half is called the **Southern Hemisphere.**

The lines of longitude are referred to as **meridians of longitude** or "**meridians,**" and if an observer were to stand facing along a meridian in a northerly direction with his arms extended, his right arm would be said to point to the **East** and his left hand to the **West.** The earth rotates from West to East.

Angular Latitude and Longitude. When considering the subject of maps, it is useful to keep always in mind the fact that latitude and longitude represent, not merely a system of lines symmetrically spaced on the earth's surface, but rather that they are essentially **angular.** Whilst the importance of this point may not be so apparent when using latitude and longitude simply to give a name to a certain point on the surface of the earth, a clear understanding of the first principles of the subject will be found essential in practical map projection, in the computation of azimuths from astronomical observations, or even in working out Great Circle angles and distances. All the above subjects are involved in practical wireless direction finding and are dealt with either in this or subsequent chapters.

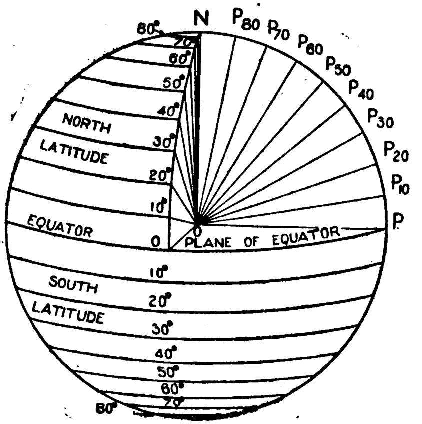


Fig. 76. Latitude.

Latitude. Let Fig. 76 represent the removal of a quadrant of the earth,

revealing the centre and a part section of the Northern hemisphere N O P. The right angle N O P is subdivided in the conventional manner into degrees, minutes ($\frac{1}{60}$ part of a degree), and seconds ($\frac{1}{60}$ part of a minute), and lines have been drawn in the figure for every tenth degree. Now, supposing each of the lines OP_1, OP_2, $OP_3 \ldots . OP_{88}$, OP_{89}, to be drawn, representing the degree divisions of **angular latitude,** then the arc PN of the earth's surface will be intersected at points P_1, P_2, P_3, . . . P_{88}, P_{89}, dividing it into 90 equal parts, which we may call "degrees" of **linear latitude.**

Circles drawn round the earth's surface, through these points P_1, P_2'', P_3, etc., and parallel to the equator, are termed the Parallels of Latitude, and between the equator and the pole there will be 89 such parallels dividing the surface of the hemisphere into 90 belts, each of which is one degree in width. These parallels are numbered off from 0° (the equator) to 90°, which corresponds to the pole, and are termed **North Latitude** and **South Latitude,** according to the hemisphere.

Longitude. Fig. 77 shows a representation of the earth with a double quadrant removed, and in this case, instead of vertical plane, consider the horizontal plane of the equator O, M_0, M_{90}, M_{180}. Much as in the previous case, the sector of the plane of the equator is divided into degrees of **angular longitude** by lines OM_1, OM_2, . . . OM_{89}, OM_{90}, OM_{91}, ... OM_{179}, OM_{180}, which lines, in turn, intersect the semicircular arc of the equator at the points M_1, M_2, ... M_{89}, M_{90}, M_{91}, ... M_{179}, M_{180}, dividing it into 180 degrees of **linear longitude.**

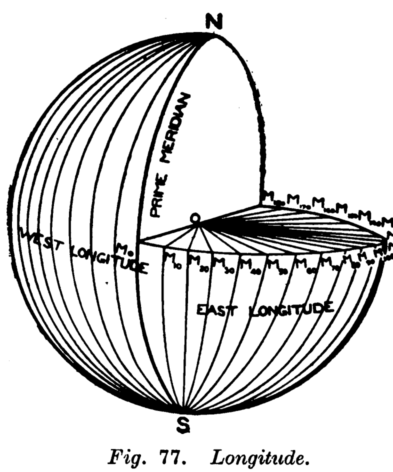


Fig. 77. *Longitude.*

Circles are now drawn through the poles and each of these points M_1, M_2', etc., as shown on the left hand side of Fig. 77, and the semicircles from pole to pole are known as **meridians of longitude.** The meridian which passes through a special

part of the Royal Observatory at Greenwich is taken as a basis for measurement of longitude and is called the **prime meridian.** The remaining meridians are numbered off from 0° (Greenwich) to 180° East or 180° West, these latter meridians being coincident.

Linear Latitude and the Nautical Mile. The linear distance on the earth's surface corresponding to one minute of arc of meridian (*i.e.*, 1 minute of latitude) is known as a **nautical mile,** and owing to the fact that the earth is not a true sphere, this distance varies slightly at different latitudes, being equal to 6,107.9 feet at the poles and 6,045.7 feet at the equator. Assuming the earth to be a perfect sphere, the length of an arc of meridian subtending 1 minute at the centre is 6,077 feet, and the nearest whole number has been taken as the **mean nautical mile,** namely, 6,080 feet, or 1·152 times the **statute mile** of 5,280 feet.

Linear Longitude and the Geographical Mile. Whilst the length of 1 minute of arc of meridian is seen to vary only very slightly in different latitudes, the length of 1 minute of arc of latitude (*i.e.*, 1 minute of longitude) varies from nothing at the poles where the meridians converge, to a maximum at the equator equal to 6,087.1 feet, and this latter is known as a **geographical mile.**

Positions on the Earth's Surface. Referring again to Fig. 76, it is seen that a point on the earth's surface which is in latitude say, 60° south, may be anywhere on a complete circle which lies two-thirds of the distance between the equator and the South Pole. On the other hand, since each meridian of longitude is seen in Fig. 77 to have a name, the statement that a point is in longitude 60° East of Greenwich, and latitude 60° South, limits its position to somewhere on a semi-circle extending from the North to the South Pole, and lying one-sixth of the distance round the earth in an easterly direction from the meridian which passes through Greenwich.

To fix the position of a point on the earth's surface, then, it is only necessary to give the latitude north or south and the longitude east or west, since each meridian intersects each parallel once and once only.

Great Circles. The Great Circle is the name given to any circle on the earth's surface, the centre of which is at the centre of the earth. Another, and perhaps more strictly accurate definition, is that the Great Circle is the intersection of the earth's surface with a plane which contains

the earth's centre. It will be seen that there may be an infinite number of Great Circles, and that they have the maximum possible diameter, which is the diameter of the earth itself. The equator is a Great Circle, since the equatorial plane contains the centre of the earth, although the remaining parallels are not Great Circles. All the meridians are Great Circles but they are, however, special cases since they all pass through the poles. Figs. 78 and 79 show two Great Circles drawn at random on the globe, and an important point to notice is that the Great Circles do not intersect consecutive meridians at the same angle. This is particularly marked in the case of Fig. 79, where the circle passes near the pole, the angles of intersection varying from a very acute angle near the equator to a right angle near the pole.

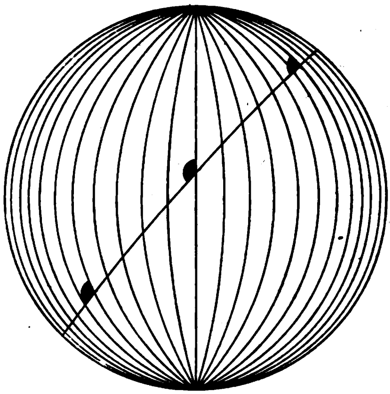


Fig. 78. *Great Circle, Illustrating Convergency.*

The difference between the angles of intersection with any two meridians is known as the **convergency**, and is an important factor in wireless direction finding work. (See page 111.)

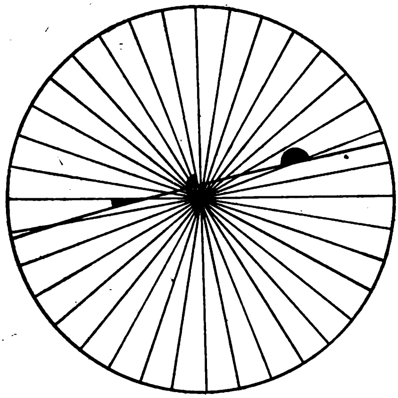


Fig.* 79.—*Great Circle, Illustrating Convergency.

Just as in the case of the plane surface, where the shortest distance between two points is the straight line joining them, so on the surface of a sphere the shortest distance between two points, measured along the surface, is the Great Circle which passes through them. Except in special cases (see Chapter 6), the direction of propagation of electro-magnetic waves on the earth's surface is

always along the Great Circle which passes through the transmitting and receiving stations, and it will therefore be realised that it is important to obtain a clear conception of the properties of Great Circles.

Maps. Since the exact reproduction of the curved surface of the earth to a large scale is not practical, it is usual to attempt to represent it on the form of a map or chart on a plane surface, but owing to the impossibility of reproducing accurately a curved surface on a plane, a certain amount of distortion is bound to take place.

There are about a dozen different types of maps in use for atlases, surveys, charts, etc., but many times this number have been prepared for the sake of special properties or combinations of properties not possessed by any one of the others. There is no special object in detailing the names of all these different methods of map projection, and space certainly does not permit of a description of them, so we will pass on to a short enquiry into the process of wireless direction finding and try to find what conditions a map must satisfy in order to be of use for this work (82).

The basic principle of wireless direction finding consists in the measurement, at a receiving station, of the angle between the direction of true north (*i.e.*, the meridian through the place) and the direction of travel of the electro-magnetic waves which are arriving from a distant transmitting station. This angle is known as the **True Bearing** of the distant

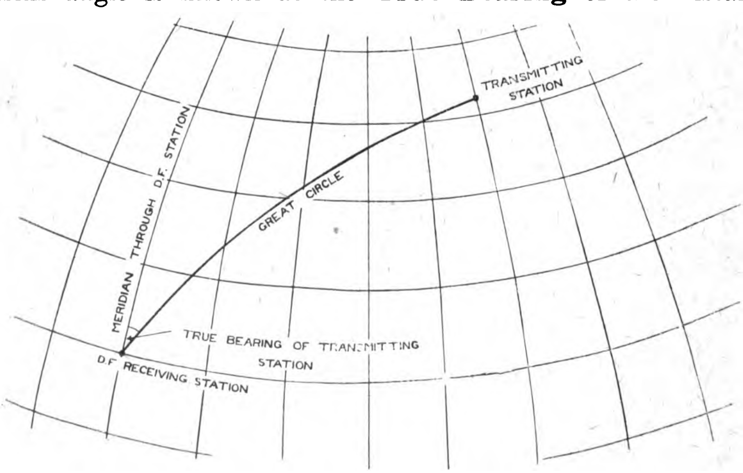


Fig. 80. True Bearing.

station, at the place, and is illustrated in Fig. 80. In some cases, particularly in the navigation of ships or aircraft by means of a direction finder installed on the vessel, it may be required to measure the angle between the directions of travel of waves from two distant transmitting stations, irrespective of their true bearings. In either cases, the angle measured is that made by the intersection of Great Circles and it is therefore necessary that the map on which the operation is reproduced must be of such a character that *Great Circles appear as straight lines.* Only when this is the case can the paths of electro-magnetic waves from transmitting to receiving station be quickly and accurately drawn and the angles measured by means of an ordinary protractor.

The Gnomonic Chart. A chart on which all Great Circles are represented as straight lines is known as **orthodromic.** If, in addition to this property, the angles subtended at a certain point of the chart, by all other points on the chart, are correctly rendered (as they would be on a globe), the chart is said to be **azimuthal.** This is sometimes incorrectly referred to as **zenithal,** which has quite a different interpretation (see page 105). Another popular name for it is the **gnomonic** projection, which, as has been pointed out by other writers (86) , does not seem to have any connection with the subject whatever ; but since there appears to be a rooted objection to calling the azimuthal projection by its correct title, the name gnomonic is probably as good as any other.

There is an optical method of producing the azimuthal or gnomonic projection of the globe which, although not representing the method by which the charts are obtained in practice, yet has the advantage of giving a very clear conception of the properties of the chart, and a short description of this may be of interest.

Suppose a light to be placed at the centre of a circular hoop as in Fig. 81, and suppose, further, that a flat surface be brought near to the hoop, or even made to touch it, forming a tangent plane. A shadow will be cast on this surface by the hoop, but since the light is in the plane of the hoop, the shadow will be a *straight line.* The position of the hoop is of no consequence ; Fig. 82 shows it turned through an angle, and the shadow is now a straight line, making an angle with the

former position equal to that through which the plane of the hoop has been turned. A moment's consideration

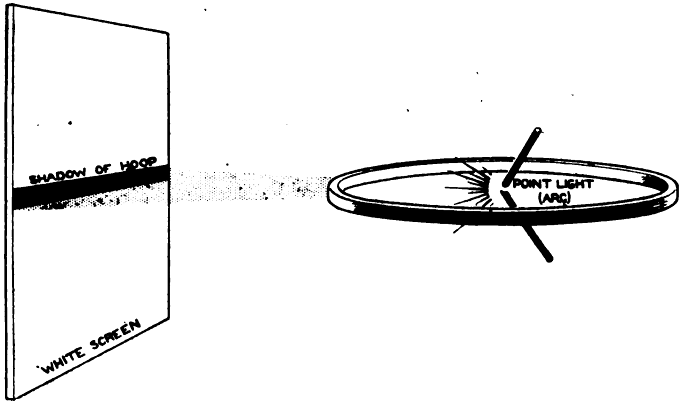


Fig. 81. *Optical Principle of Gnomonic Projection.*

will show that no matter what the position of the hoop, the shadow thrown on a plane surface by a light at the centre will always be a straight line.

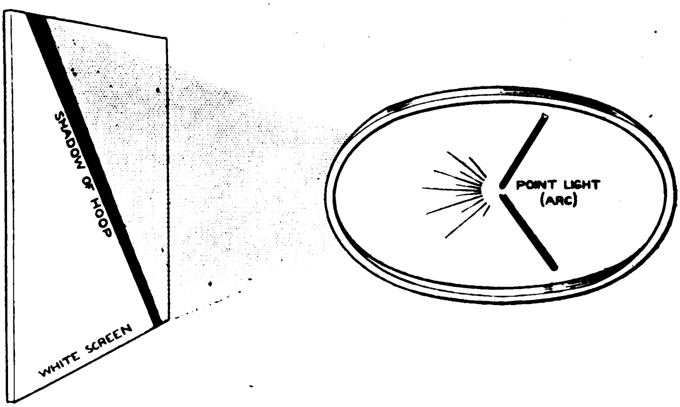


Fig. 82. *Optical Principle of Gnomonic Projection.*

Fig. 83 shows a transparent model globe of the earth, which has a light at the centre. On this globe are marked the lines of latitude and longitude, and if a tangent plane be applied at, say, the point O, then the shadows of all great circles, whether they pass through O or not, will appear as straight lines for the reasons given above in connection with

the hoop. This means that all the meridians of longitude will be straight lines, and if any random great circle be drawn through O, this will be projected on the tangent plane as a

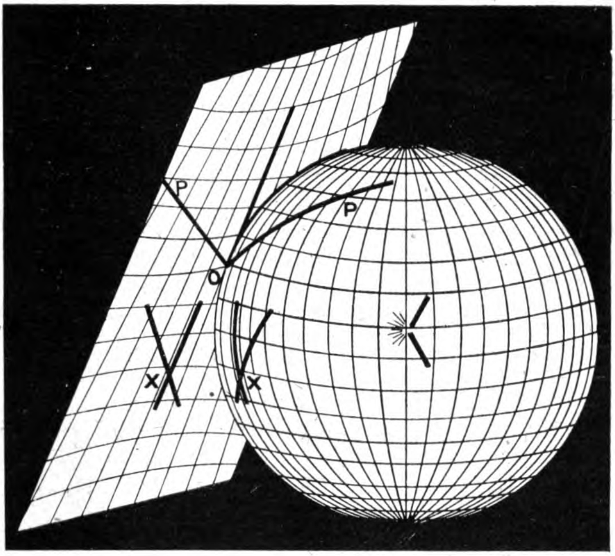


Fig. 83. *Gnomonic Projection by Optical Means*

straight line OP and, what is more important, the angle between the great circle and the meridian through O is correctly reproduced in the shadow map.

The point O is known as the **Point of Contact** since it is the point where the surface of the globe and the tangent plane touch. This is the only point at which the angles of intersection of great circles are correctly rendered, although the errors at other points, for instance at the point X, are only of the order of a few minutes of arc in the charts which will be used for practical D.F. work.

Fig. 84 shows the relative disposition of the tangent plane for a gnomonic chart extending over 25° of latitude and the portion of the globe which it represents. From this diagram it will be seen that the distance L M is slightly greater than the corresponding distance *lm* on the globe, and that this discrepancy will increase rapidly as the distance from the point of contact P increases. For this reason, the charts are not zenithal; that is to say, great circle distances between

points on the chart cannot be scaled off accurately, although the errors are not greater than about 1% or 2% in the gnomonic charts, which will be used for D.F. work. A chart can be constructed which is both azimuthal and zenithal (51).

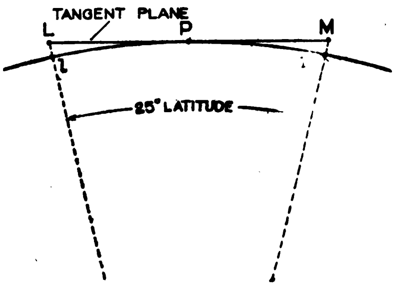


Fig. 84. *Zenithal Properties of Gnomonic Projection.*

It may be interesting at this point to study the various forms which the charts will take when the point of contact is taken at different positions on the earth's surface. Suppose, for instance, the point of contact to be taken at the pole. The meridians will then be straight lines, radiating from the point of contact, since they are actually great circles passing through the pole, and the parallels of latitude will appear as concentric circles about the pole, as shown in Fig. 85. Again, if the point of contact be taken, say, in latitude 45°N., the chart will appear as in Fig. 123, and so on, the meridians becoming nearer and nearer to parallel straight lines as the point of contact gets further from the pole, until, when it reaches the equator, the meridians are parallel straight lines and the parallels are very flat curves, convex to the straight line through the point of contact.

It will be seen that the meridian on which the point of contact is taken does not affect the appearance of the chart at all; only the latitude of the point can do this. The result is that the chart which in Fig. 123, Chapter 5, is seen to extend from 37° 30′ to 52° 30′ north latitude, may be used for any part of the globe within this zone of latitude in the northern hemisphere, and if turned upside down could be used for the corresponding zone in the southern hemisphere. It is, therefore, a fairly simple matter to have a set of gnomonic charts available for any part of the globe.

The Gnomonic Graticule. In preparing such a series of charts. each of which is suitable for a given belt of latitude, it will clearly be an advantage to have no coast lines or physical features whatever marked on the chart, and only the lines of latitude and longitude. Such a network of parallels and meridians is known as a **graticule,** as distinct from a map or chart. (The more popular, if less strictly accurate name

of " chart " will be used throughout the book, except where it might lead to confusion.) As mentioned above, the

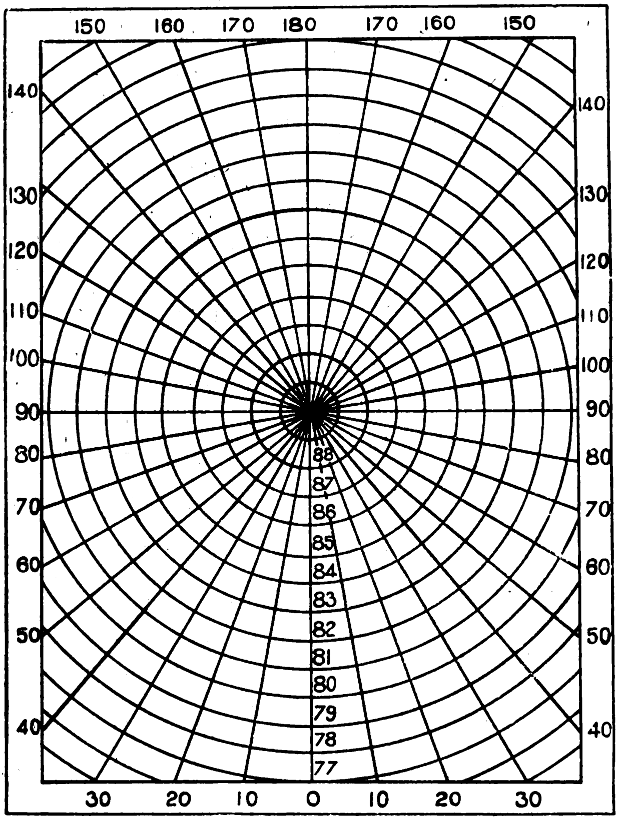


Fig. 85. *Gnomonic Chart with Point of Contact at the Pole.*

gnomonic graticule is a function of the latitude only, and may be used in any longitude, and it is therefore usual to print only the values of the latitude and to leave the meridians blank, so that they may be given values later, depending on the part of the world in which the chart is to be used.

25 Miles to the Inch Gnomonic Charts (Graticules). Such a series of gnomonic charts have been prepared by the Marconi Company for use in shore D.F. stations and also, if desired, for use in wireless navigation on ships. (The method of construction of a gnomonic graticule is described

on page 346.) There are twelve of these charts, and Fig. 86 shows the twelve tangent planes in their position on a globe, from which it will be seen that a chart is allotted to every 10° of latitude, the number of degrees of longitude depending on the latitude. The point of contact is taken at the centre of the tangent plane, but is not shown in the finished chart. The overlap of the charts, which is not shown in the figure, is 2° 30′ of latitude, both north and south, so that the total range of latitude is 15°.

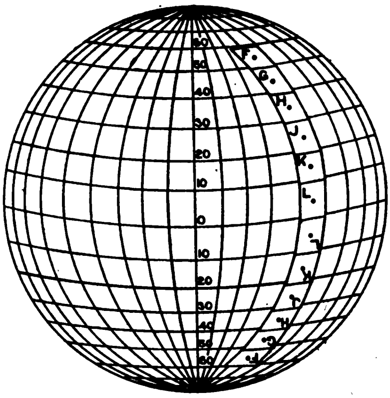


Fig. 86. *Tangent Planes of a Series of Gnomonic Graticules.*

Particulars of the complete series are as follows :—

NAME.	LIMITS OF LATITUDE.	
	North.	*South.*
F	62° 30′ N. ..	47° 30′ N.
G	52° 30′ N. ..	37° 30′ N.
H	42° 30′ N. ..	27° 30′ N.
J	32° 30′ N. ..	17° 30′ N.
K	22° 30′ N. ..	7° 30′ N.
L	12° 30′ N. ..	2° 30′ S.
L (Reversed) ..	2° 30′ N. ..	12° 30′ S.
K ,, ..	7° 30′ S. ..	22° 30′ S.
J ,, ..	17° 30′ S. ..	32° 30′ S.
H ,, ..	27° 30′ S. ..	42° 30′ S.
G ,, ..	37° 30′ S. ..	52° 30′ S.
F ,, ..	47° 30′ S. ..	62° 30′ S.

Note that the charts for the southern hemisphere are obtained by reversing the corresponding charts of the northern hemisphere, the numbering of the latitude being arranged so that the figures in the *left-hand margin* always read the correct way up for the chart. (See Fig. 123.) The method of using the gnomonic graticule is described on page 133.

The Retro-Azimuthal Chart. There is another one of the family of map projections to which the gnomonic or azimuthal projection belongs, which is worthy of note, though

it is not proposed to deal with it at any great length. We saw that the gnomonic projection had the property of rendering all great circles as straight lines, and the correct azimuths of all points on the chart *from a certain point* which was called the "point of contact." It is possible to produce such a projection that all great circles appear as straight lines and the azimuths of either one or two certain points on the chart *from all other points* are rendered correctly. The names given to this type of chart are **Retro-Azimuthal** and **Bi-Retro-Azimuthal** respectively, depending on whether the chart is retro-azimuthal with respect to one or two points. The projection has great possibilities in connection with navigation over long distances between high power wireless stations, but the construction of the chart will not be considered in any detail, as it may be considered to be beyond the scope of this book in its present form.

The Orthomorphic Cylindrical Projection or Mercator's Projection. In the foregoing remarks on the selection of a chart for direction finding, no allusion has been made to the Mercator's chart, which is probably one of the best known methods of representing the earth (with the exception of the polar regions), on a single sheet, and which is almost universally used for nautical charts.

This map is one of a class called "cylindrical projections," and it is possible to obtain a fairly clear conception of some of its properties by considering the method in which a type of cylindrical projection may be obtained by the optical method, making use of the transparent globe with a light at the centre.

Reverting to Fig. 83, we saw that if the tangent plane were made to touch the globe on the equator, the meridians were all projected as straight lines and the parallels were curves, convex towards the equator. Suppose, now, that the surface on which the projections have been made, and which hitherto has been assumed to be a plane, be bent into the form of a cylinder, making line contact with the surface of the globe, along the equator. An investigation of Fig. 87 and a few moments consideration will indicate that, whilst the meridians are still projected as straight lines, the parallels of latitude are now projected as parallel circles. The distance between successive parallels on the cylinder is seen steadily to increase with the distance from the equator, and it is not possible to reproduce the polar regions, since the pole itself will be at an infinite distance.

If this cylinder be now opened out, we have a chart similar to that shown in Fig. 88, and which suffers from several disadvantages. In the first place, the only part of the map at which the scales of latitude and longitude are the same is along the equator. It is clear that the scale of longitude must increase as we approach the pole, since the meridians are parallel in this map, whilst actually we know they converge towards the pole. In the same way the scale of latitude is rapidly increasing as we move away from the equator, since the poles are at an infinite distance from the equator on the map. These two scales are also increasing at different rates, with the result that at any point on the map a distance of, say, ten miles, measured east and west, and a similar distance measured north and south, are represented on the map by quite different lengths; so that if the projection were used for a map of the world, all the countries would be grossly distorted in shape, and even the smallest angles or bearings, as measured on the map, would be incorrect.

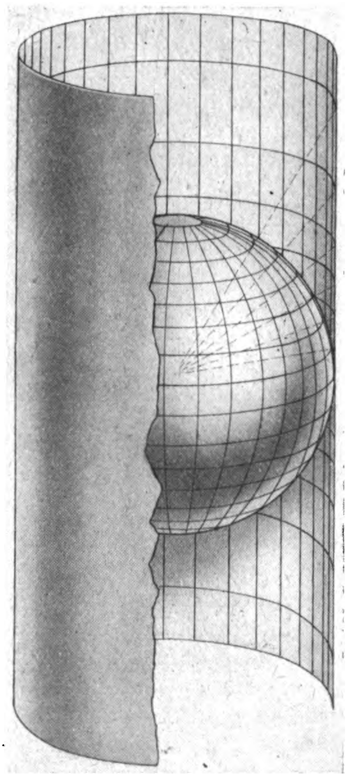


Fig. 87. Cylindrical Projection by Optical Means.

The cylindrical projection shown in Fig. 88 is therefore modified in such a manner that at any given point the scale of latitude and longitude is the same, the chart becoming what is known as **orthomorphic**, or capable of representing small areas in their correct shape, and this is the **Mercator's projection**.

Distances on a Mercator's Chart. Since the scale of both latitude and longitude varies with the latitude, it is

not possible to use any fixed scale in the measurement of distances between places unless they lie on the same parallel. On all nautical charts, however, the latitude is marked in the

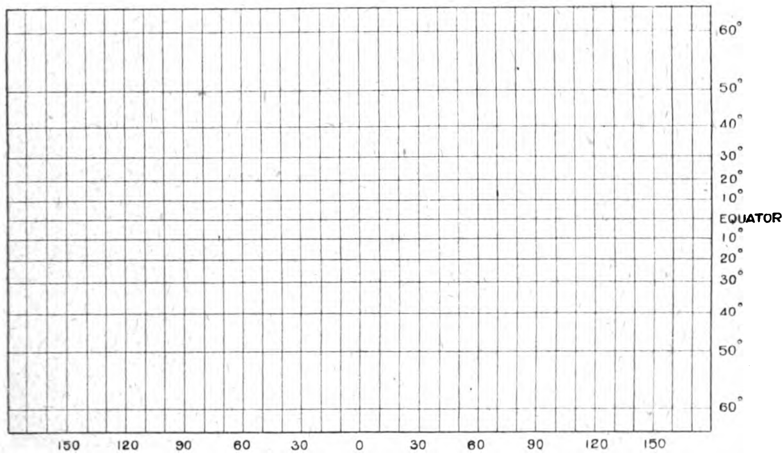


Fig. 88. *Development of Cylindrical Projection of Fig.* 87.

margin on both sides of the chart, the degrees being subdivided into minutes of linear latitude which, it will be remembered, correspond to nautical miles. It is thus only necessary to set a pair of dividers to the distance on the chart to be measured, and use as a scale that portion of the marginal latitude scale which most nearly coincides with the latitudes of the points under consideration.

Comparison of Properties of Gnomonic and Mercator's Charts. In Fig. 89 is shown the globe, or small scale model of the earth, which is the only "map" which retains all the geometrical properties of the earth itself. A portion of this sphere is lined in from 20° East to 20° West longitude and from 20° to 50° North latitude. Two points on the surface

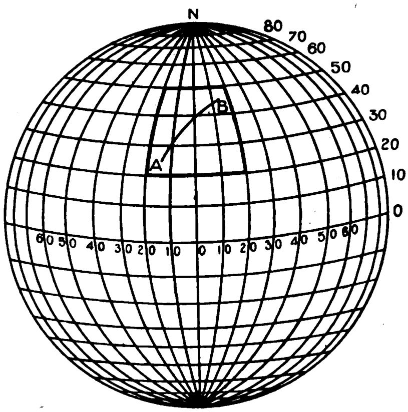


Fig. 89. *Great Circle on Globe*

are shown at A and B, which have positions respectively 15°W., 25° N. and 15° E., 45° N. Figs. 90 and 91 show the same portion of the earth's surface on the gnomonic and Mercator's charts, and the following comparison of the three "maps" will illustrate characteristics of the last two, as compared with the first.

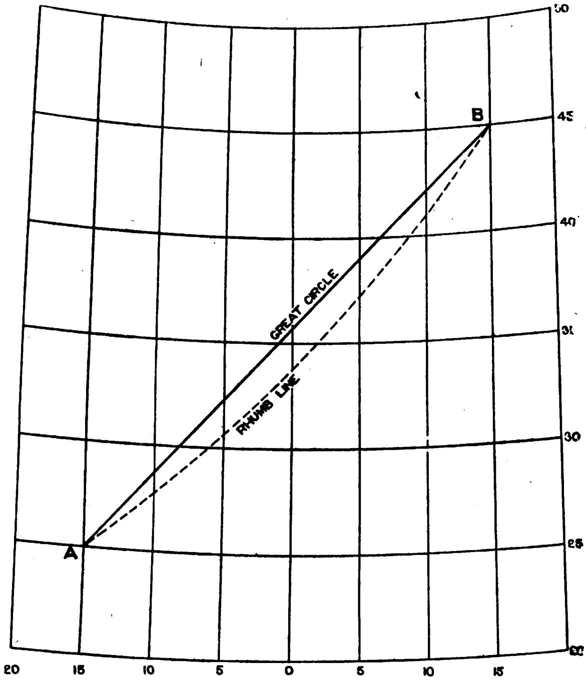


Fig. 90. *Great Circle on Gnomonic Chart.*

Suppose a Great Circle to be drawn from A and B ; on the globe this will appear to be a curve, owing to the perspective of the drawing, though we know that actually it is the shortest distance along the surface from A to B. On the gnomonic chart it is a straight line, and we notice that, as we have already found, it cuts successive meridians at different angles, just as it does on the globe.

There is no simple way of drawing a great circle on a Mercator's chart, and the easiest way in this case will be to plot off on the Mercator's chart, the points on the gnomonic chart or the globe, where the great circle cuts the meridians. If this be done, the resulting great circle will be as shown in

Fig. 91, namely, a curved line which is concave to the equator. (A method of drawing great circles on a Mercator's chart when a gnomonic chart is not available is given on page 344.)

The angles at which this line cuts respective meridians will be found to be the same as in the other two figures, but owing to the meridians on the Mercator's chart being parallel, the great circle must of necessity appear curved.

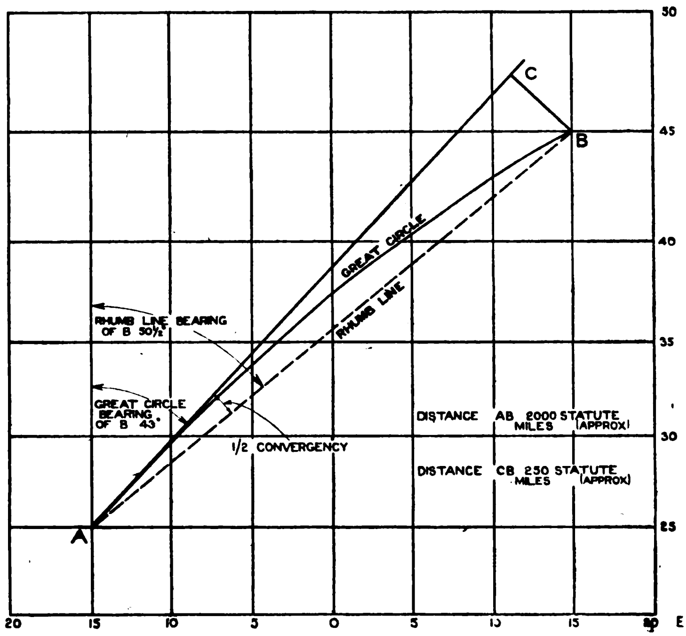


Fig. 91. *Discrepancy between Great Circle Bearing and Mercatorial (or Rhumb Line) Bearing.*

Consider, now, what would be the result of using a Mercator's chart for long distance direction finding work. Suppose that in Fig. 91, A represents the position of a D.F. station and B that of a transmitting station. The path of the wave from B to A will be along the great circle, and the apparent direction from which it is arriving at A will be along the tangent to the great circle at A, which is the line AC. On the map, the direction of the transmitting station is along the line AB, the error being seven or eight degrees, and the line AC passing B at a distance of about 250 miles.

The angle CAB is equal to one half of the difference between the angles of intersection of the great circle with the meridians through A and B, and is called the **half-convergency.**

Rhumb Line. Any line which cuts successive meridians at the same angle is called a rhumb line, and since, in the Mercator's chart, the meridians are parallel straight lines, the rhumb lines are also straight lines.

The equator is a rhumb line, since it cuts all meridians at right angles, but it is a special case in that it is also a great circle. The rhumb line track is one usually adopted by ships when time is not of paramount importance, since it involves less trouble in ascertaining the correct course on which to set the ship. If the great circle track be followed, the course will have to be constantly changing, since the bearing of true north varies at every point of a great circle. The dotted line in Fig. 91 shows the rhumb line track, and similarly in Fig. 90, where, owing to the fact that the meridians are not parallel, it appears as a curve, which in fact it is on the surface of the earth, in every case except when the two extremities of the line lie either on the same meridian or on the equator.

Limitations of the Mercator's Chart for D.F. Work. For distances between receiving and transmitting stations up to about 100 miles, the rhumb line and great circle lie fairly close to one another, and a Mercator's chart may be used for D.F. work with only comparatively small errors. With increasing distance between the stations the discrepancy rapidly increases, and for accurate work a gnomonic chart must be used, unless a correction for half-convergency be applied to the apparent bearings found from the Mercator's chart.

For shore work, gnomonic charts will almost invariably be available for long range working, but the inconvenience of carrying this type of chart at sea to suit the variety of latitudes in which the vessel may be, during a long voyage, has resulted in a tendency for ship's navigators to rely on short range D.F. bearings of 100 miles or less, in which case they are able to use the standard nautical charts.

Correction of Azimuthal Errors in Mercator's Chart. If, for any reason, a long range station is used, either for calibrating or navigating purposes, when a gnomonic chart is not available, a correction for half-convergency may be applied. In the first case it may be applied to the rhumb line bearing

as read off from the Mercator's chart, in order to convert it to the great circle bearing as observed on the D.F. In the second case of a bearing taken, say, by a ship D.F., of a distant transmitting station, the correction may be applied to the observed bearing in order to find the rhumb line bearing, so that the latter may be laid off on the Mercator's chart and used in order to find the ship's position by methods which will be explained in Chapter 5.

A simple formula exists for calculating the half-convergency and gives results which are accurate to within 10′ of arc at distances between the transmitting and receiving stations of 1,200 miles :—

$$\text{HALF-CONVERGENCY} = \tfrac{1}{2}\left[\begin{array}{c}\text{Difference of Longitude}\\ \text{between transmitting}\\ \text{and receiving stations.}\end{array}\right] \times \left[\begin{array}{c}\text{Sine of the Middle}\\ \text{Latitude between}\\ \text{the stations.}\end{array}\right]$$

The half-convergency is zero when either of these factors vanish, and this is clearly correct when the difference of longitude between the stations is zero, since when this is the case the stations must both lie on the same meridian, which is, of course, a great circle. When the middle latitude is zero (equator), there still remains a slight amount of convergency which, however, may be neglected in all practical cases. The Mercator's chart might be expected to be azimuthal in the neighbourhood of the equator, as it will be remembered that in the optical method of producing the cylindrical projection, from which this chart is developed, line contact with the globe occurred along the equator.

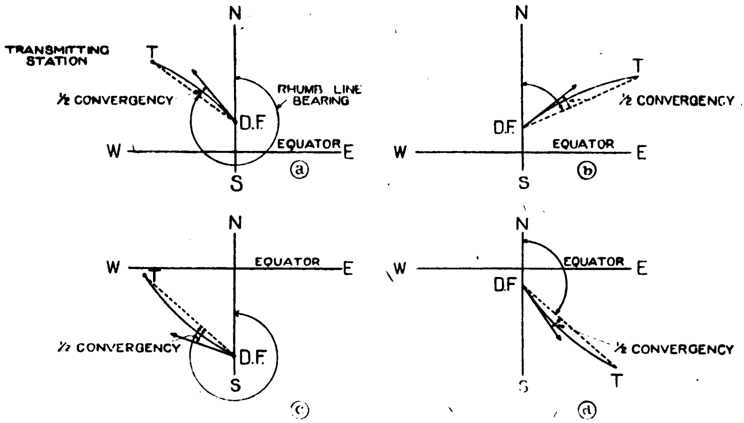


Fig. 92. Sign of Half-Convergency.

Sign of the Half-Convergency. The sign of the correction, that is to say, whether it must be added or subtracted, will depend on the relative positions of the two stations and also on whether it is required to convert rhumb line bearing to great circle bearing or vice versa. Bearing in mind that the great circle is always concave towards the equator, we can draw a series of diagrams which illustrate how the varying positions of the stations affects the sign of the half-convergency (Fig. 92), and tabulate the results as follows :—

	Middle Latitude.	Transmitting Station.	Given the Great Circle to convert to Rhumb Line.	Given the Rhumb Line to convert to Great Circle.
(*a*)	**North**	**West of D.F.**	**Subtract**	**Add**
(*b*)	**North**	**East**	**Add**	**Subtract**
(*c*)	**South**	**West**	**Add**	**Subtract**
(*d*)	**South**	**East**	**Subtract**	**Add**

Note.—All bearings to be expressed in ***degrees east of north*** before applying the correction.

Examples are given in the application of this correction in Chapter 5, both in the case of the calibration of a shore D.F. station and also in ship navigation.

Half-Convergency Diagram. In order to obviate the necessity of arithmetic in connection with the use of the above formula when a number of values of half-convergency are required, an alignment chart has been constructed by the author and is reproduced, together with instructions for its use, as a frontispiece.

The Line of Bearing. It was seen in Fig. 91 that when using the Mercator's chart for D.F. work over large distances, the apparent direction of a transmitting station B from the D.F. station at A was, in the majority of cases, entirely wrong. Referring now to Fig. 93, let this again represent the conditions of Fig. 91, with the great circle through A and B shown as a full line, and the rhumb line as a broken line. Suppose that whilst the rhumb line bearing of B from A is $50\frac{1}{2}°$ east of north, the angle of arrival of the wireless signals along the great circle makes it appear to be 43°, *i.e.*, along the tangent A C to the great circle.

If successive points be taken along the great circle at A_1, A_2, etc., (Fig. 93) indicating the position of the receiving D.F. station as it approaches B along a great circle course, the angle which the great circle makes with the meridian at the points A_1, A_2, etc., will increase steadily until it reaches B.

Now suppose that Fig. 94 represents the same process,

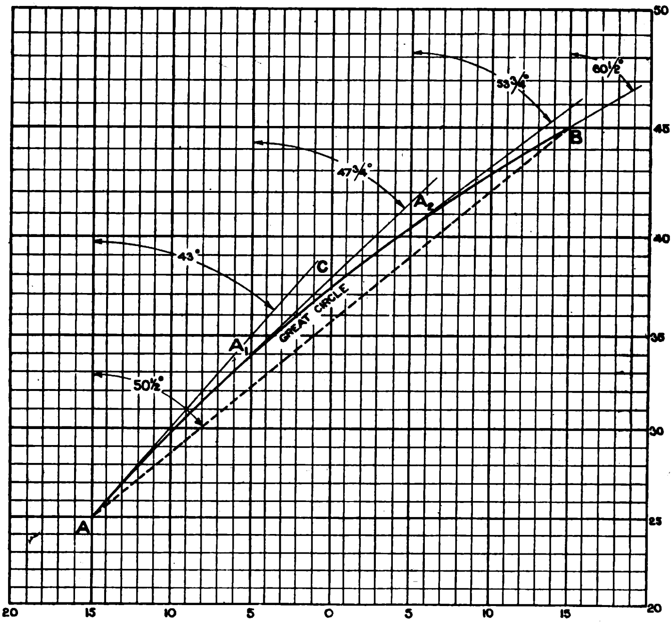


Fig. 93. Change in True Bearing as A approaches B along Great Circle.

except that A approaches B along the rhumb line. Again we see that the bearing of B from successive positions of A steadily increases, although to a less extent than before.

There must, however, be some such line that if A approach B along this course, the angle between the tangent to the great circle and the meridian at the point will be constant, and Fig. 95 shows the path of such a line. An inspection of this diagram will show that at every point along the line A, A_1, A_2, B, the bearing of B is constant and equal to 43°, and this line is called a " line of constant bearing," or simply a **line of bearing.**

For short distances between the points A and B, the line of bearing and the great circle lie symmetrically on either side

of the rhumb line, so that the angle of intersection of these curves is equal to the convergency between A and B.

The lines of bearing of any point, if completed, are found to converge on the pole, the line BA having been drawn in full in Fig. 96.

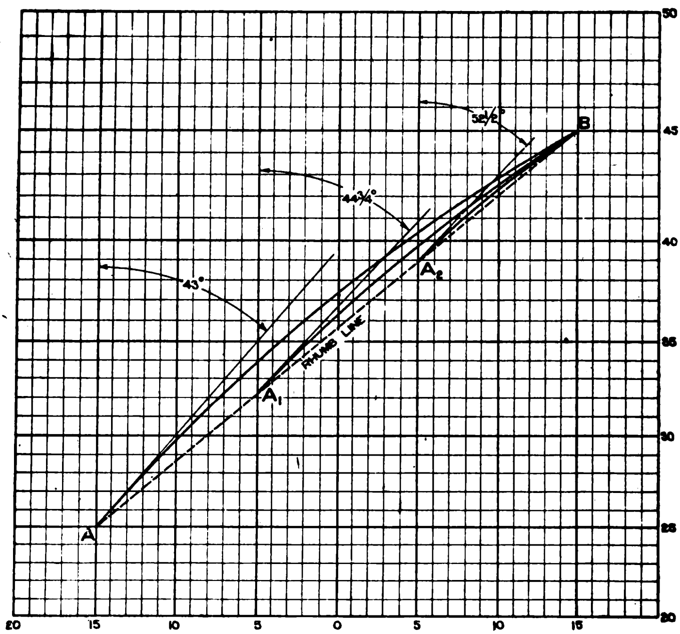


Fig. 94. Change in True Bearing as A approaches B along Rhumb Line.

If lines of bearing were marked on a Mercator's chart for every degree, in connection with a number of high power wireless transmitting stations, such a chart at once assumes important properties from the point of view of wireless navigation by the D.F., which are lacking on the ordinary Mercator's chart, and to which reference will be made in the next chapter (page 138).

It will be seen that this type of map, on which navigation is achieved by making use of lines of bearing on two or more wireless transmitting stations, is very much akin to the retro-azimuthal type already mentioned. The latter has the advantage that the lines of bearing are straight, but on the other hand the chart has to be specially drawn for the

district, and is only correct for two points. The Mercator's chart has the disadvantage that lines of bearing are curves, which have to be carefully plotted by a rather laborious process,

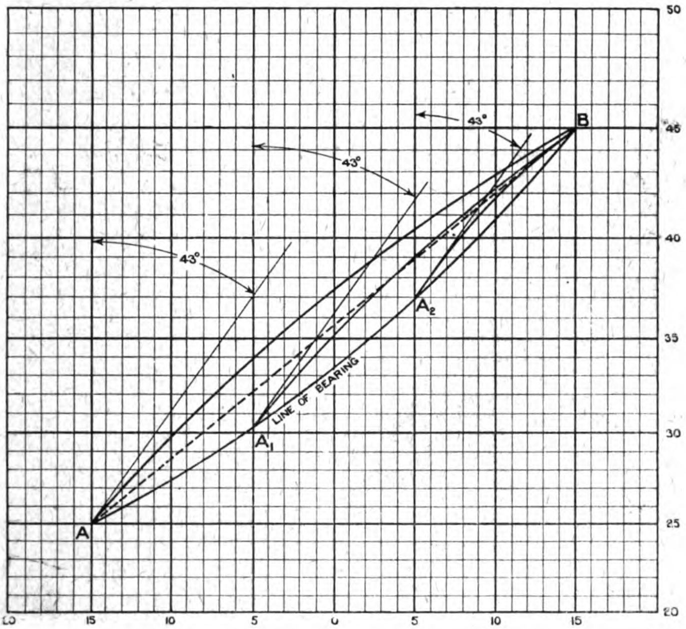


Fig. 95. *Line of Constant Bearing.*

but against this are the advantages that Mercator's charts are almost universally procurable, and lines of bearing may be drawn for as many stations as required.

British Ordnance Survey Maps. In Chapter 7, when describing the geographical method of obtaining the direction of the meridian through a shore D.F. station, the use of an Ordnance Survey is involved, and a few notes on this series of maps may be of interest. We saw that the Mercator's chart was not a true projection in that the scale of latitude was subsequently modified in order to make the chart orthomorphic. The method of construction used for the six-inch Ordnance Survey maps of the British Isles is still less amenable to simple illustration, being chiefly a mathematical process. The properties of the maps are, however, important. The small

sectional maps of the "six-inch survey" are really all parts of one huge map which extends over the whole area of the survey, so that it follows that adjacent sections may be joined together accurately. There are some slight disadvantages in the use of "Projection by Rectangular Co-ordinates," which is employed in this survey; one of these being that the scale in a north and south direction is not strictly accurate in certain parts of the map, but owing to the relatively small distances involved, this defect is not very apparent. A further defect is that the meridians are not straight lines, but are curves of very large radius, and although the curvature is scarcely noticeable, this characteristic is indirectly responsible for many errors being made in the use of the maps. Since the whole survey is divided up into sectional maps, which are rectangular in shape, it follows that, owing to the curvature

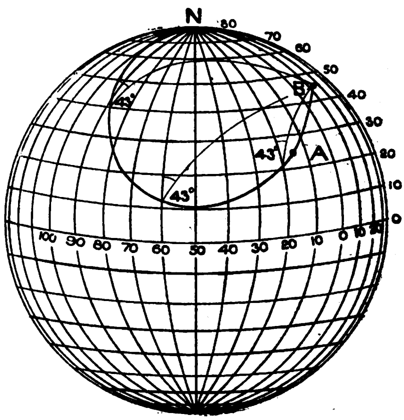


Fig. 96. 43° *Line of Bearing with respect to B.*

of the meridians, they are only in rare cases parallel to the edges of the sectional maps, and the discrepancy may be as much as 4° (82). When using the survey maps to obtain the direction of the meridian (page 207), care should always be taken to make use of the scale of longitude, which is marked along the upper and lower margins, and not to assume that the meridian is parallel to the edge of the sheet.

CHAPTER 5.

POSITION FINDING.

It has already been stated in Chapter 1 that the position of a wireless station can be found by means of the wireless direction finder in a number of ways, and in every case it was seen that the exact position of the station was at the intersection of two or more lines, the direction and position of which were ascertained by wireless means. It is now proposed to enquire more deeply into the problem of wireless navigation.

Although the station, the position of which it is desired to find, may be either a ship, aircraft or mobile land station, it will, for the sake of simplicity, be referred to as "the ship," unless, of course, some special point in connection with an aircraft or shore station is being considered.

Position finding by directive reception may be accomplished by either of two distinct methods :—

(*a*) The ship is fitted with ordinary wireless transmitting and receiving apparatus, bearings being taken by shore direction finding stations which thereby locate her position and communicate it to her by wireless.

(*b*) The ship is fitted with her own direction-finding apparatus, and it is thereby possible to find her position without the aid of special wireless communication, by means of bearings taken on ordinary shore transmitting stations, the positions of which are known.

It should be noted that if in case (*a*), only one shore D.F. station, or if in case (*b*), only one shore transmitting station be available for obtaining bearings, the position of the ship cannot, in general, be found by purely wireless means (except by such methods as the "Running Fix," page 151). The "bearing" of the ship from the station can be obtained, but other data is necessary to give an actual position.

THE SHORE DIRECTION-FINDING STATION.

The various cases of position or direction finding which involve the use of either one, two, three or more shore D.F. stations for the purpose of locating a mobile transmitting station, will

now be dealt with in turn. Each case will be illustrated by a suitable map diagram indicating the limitations of the method.

Case 1. Position Line by Means of One Shore D.F. Station. Let Fig. 97 represent an imaginary coast line with a port at P, a bay with islands at X and Y, and a D.F. station at some point A, which has been calibrated so as to read the bearings of incoming signals in degrees east of true north.

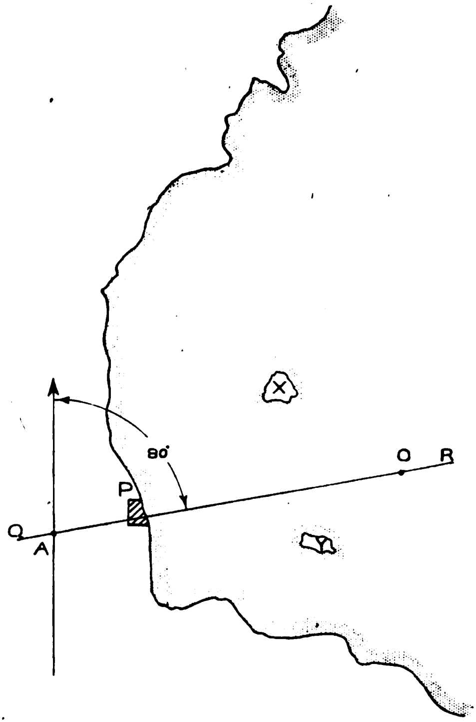


Fig. 97. Position Line from single shore D.F.

Suppose O to be a ship which is either coasting or making for the port P, and that, owing to fog or other reasons, she decides to obtain her bearing from the D.F. station at A, the position of which is known to her. The exact wireless procedure to be adopted will depend upon the country, but the operations involved may be outlined as follows :—

Having attracted the attention of the D.F. station, the ship will be told to transmit for a period of about one and a half minutes, and since medium strength clear signals are required for accurate work, care should be taken to keep the note and strength as steady as possible and not to use too great a power. During this time A obtains the direction of the incoming signals, and we will suppose this to be 80° east of north, which means that if a straight line be drawn through A, as shown in Fig. 97, making an angle of 80° east of the meridian through A, then the ship which is transmitting must lie somewhere on that line. What actually occurs is that the telegraphist at the

D.F. station, having ascertained this angle or bearing, transmits the result to the ship, and the navigating officer of the ship himself plots out the line QR on his chart. This line is called a **position line** and is the only information which can be obtained from a single D.F. station.

If the distance of the ship from A is known to be a few miles only, an ordinary nautical chart may be used for plotting the position line, but for distances greater than 100 miles or so a correction for convergency must be applied in the case of a Mercator's chart, or else a gnomonic chart must be used, if the position line is to be accurate. The convergency correction involves a knowledge of the approximate position of the ship, and the alternative is to carry on the ship special gnomonic charts or graticules for all latitudes in which it is anticipated that wireless bearings may be wanted. As a rule, the approximate position of the ship will be known to within a few miles, thus enabling the nautical chart to be used. A set of gnomonic graticules, however, such as those described in Chapter 4, would prove useful in an emergency when the ship has been sailing by "dead-reckoning" for a considerable time, in a part of the world where the tides and currents are variable.

As a general rule, however, bearings are not often taken over great distances, and the ordinary Mercator's chart, with uncorrected bearings, would be quite satisfactory for use in making a port or coasting within a few miles of the shore. As the ship nears land, and hence runs greater chances of getting into danger, she will usually also get nearer to the D.F. station, with corresponding increase in the accuracy of the bearings as measured on an ordinary nautical chart, as the convergency becomes negligible.

Case 2. Cross Bearings by Means of Two Shore D.F. Stations. In Fig. 98, the ship O is again seen approaching the port P and, we will assume, has obtained a position line QR as before, from the station A. Suppose now, a second D.F. station be placed at B, then by adopting the same procedure as before, a second position line TS will be obtained, corresponding to the bearing of, say, 170°.

The procedure in this case would be much the same as before, except that it would be necessary to include the call signs of both D.F. stations, and also to ensure that both stations took their bearings at the same time. (Allowance can be made for any discrepancy in this respect, when using the ship D.F. (page 146).) Immediately after sending the

arranged signals for the purpose of taking bearings, the ship would stand by for the bearings from the two D.F. stations, which would be transmitted in the form of a number representing the bearing of the ship east of north from the station in each case. These results would enable the two position lines QR and TS to be plotted on the chart, and the position of the ship would therefore be found by their intersection. This is called a **Fix.**

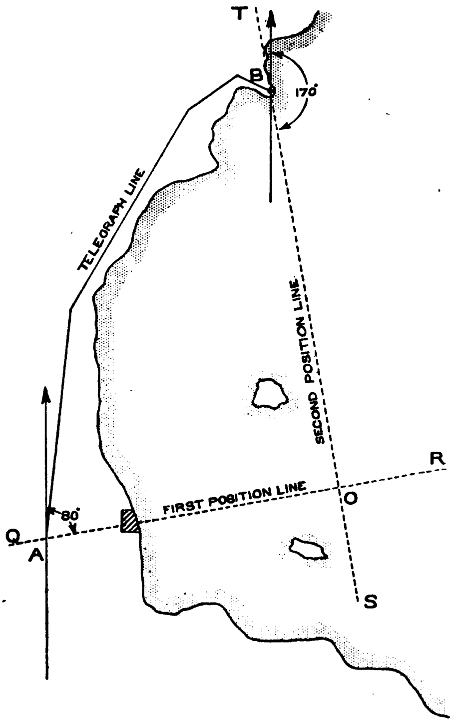


Fig. 98. *Fix from two shore D.F. stations.*

Case 3. A Fix by Means of Two Associated Shore D.F. Stations. If, instead of being independent stations, A and B are in communication with one another by means of wireless—or, better still, by land wire telegraphy or telephony, in order to reduce the amount of wireless transmission—the work of laying off the two position lines may be done ashore, and the resulting fix transmitted to the ship in the form of a latitude and longitude or else a bearing and distance from a given object, such as a buoy, lightship, or well-known part of the coast. On the assumption in Fig. 98 that the station A is a controlling station, and that B is a second D.F. station working in conjunction with A, it is not necessary to know the positions of the two stations, but only the call sign of the controlling station A.

Accuracy. The primary claim for wireless navigation is that it is an emergency method of finding the ship's position when, through some cause or another, other methods partially or totally fail. Intelligently used, the wireless direction finder will give good results, and large errors need not be anticipated;

however, "forewarned is forearmed," and it will be of interest to inspect the degree of accuracy which can be expected in a scheme such as that illustrated in Fig. 98.

Some idea of the possible discrepancies is given in Fig. 99 between the real position of the ship and that given by a D.F. with an error in the taking of the bearing of 1° either side of the true value. A small quadrilateral has been shown black at the position O, and this represents the area of doubt.

In Fig. 100 the port P is shown on a map drawn to a smaller scale, so that the accuracy of the D.F. fix may be investigated when the ship is at a considerable distance from the stations. The smallest areas are seen to be when the position lines from A and B intersect at right angles, as at O_1. As the angle of intersection becomes more acute, due to the increasing distance of the ship from the stations, as at O_2 and O_3, or else due to its approaching a position on a line passing through the stations, the area of doubt increases until, when the ship is at some position O_4, she may be said to be beyond the range of accurate position finding by means of the stations A and B alone.

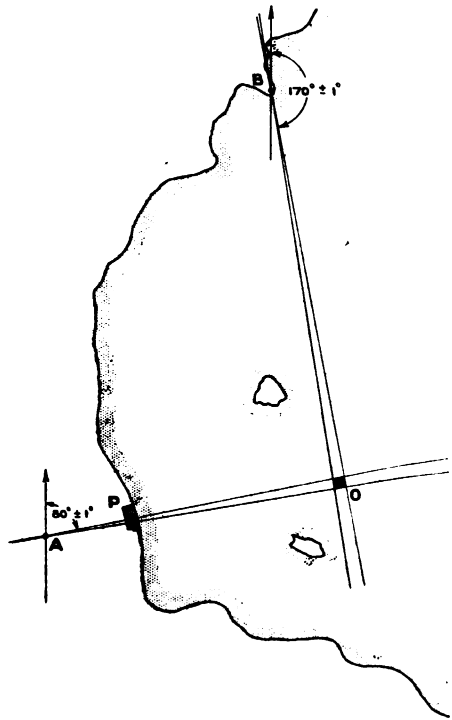


Fig. 99. Degree of accuracy of Wireless Fix.

In thick weather, however, it might at times be very useful to be able to locate the ship within an area even as large as that at O_4.

Case 4. A Fix by Means of Three Associated Shore D.F. Stations. Suppose, now, that the case illustrated in Fig. 100 be modified by the addition of a third station at C, as

in Fig. 101. The field of accurate work is now greatly increased, since it becomes possible to get position lines from C to intersect those from A and B at such places as O_3 and O_4, the reduction in the area of the quadrilateral at O_4 being particularly noticeable. In practice it is customary to use three D.F. stations to work on each area, so that one of them may act always as a check on the other two, and also give the increased accuracy which has just been noted. During the European War it was common practice to use four stations on each area in order that reliable "snap" bearings might be taken with the minimum chance of error (19).

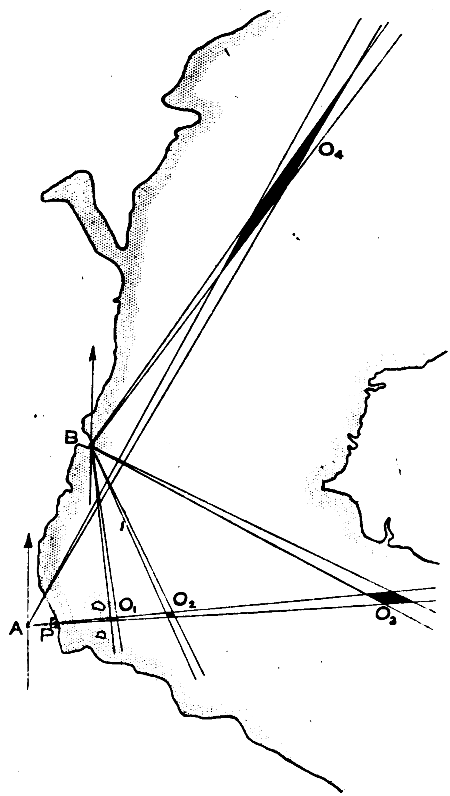


Fig. 100. *Variation in accuracy of Wireless Fix with relative position of ship and D.F. stations.*

This third station at C will still be under the control of A, and in this case will presumably communicate readings by wireless means unless a land wire can be run by some circuitous route.

The procedure, so far as the ship is concerned, will be the same as for the two associated D.F. stations already described in Case 3, and a slight modification only is necessary in the routine of the control station.

General Procedure. The exact procedure to be followed when obtaining bearings from shore direction-finding stations—both single stations and associated groups of stations—will shortly be standardised by International agreement, but in the meantime each country is publishing regulations governing the use of its own D.F. stations (87). These regulations are pub-

lished in the form of "Notices to Mariners" by the British Admiralty; the Department of Marine, Canada; the U.S. Navy Department, etc., but a considerable amount of information on the subject, in a rather abridged form, is to be found in "The Admiralty List of Lights, Time Signals," from the 1921 edition of which we have reproduced, by kind permission of the Hydrographer of the Navy, several pages concerning the D.F. stations of the United States of America. The "Additional Details" on the right-hand pages are of interest, and are fairly typical of shore D.F. station organisation. An example of a co-ordinated group of D.F. stations is seen on page 130, namely those at San Francisco.

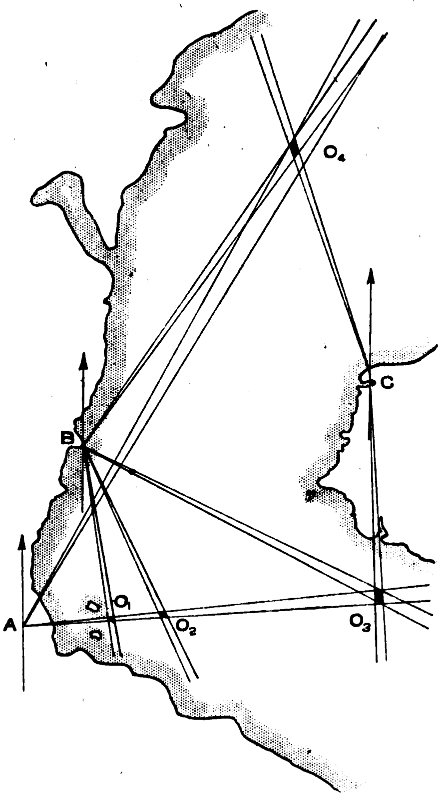


Fig. 101. *Increase in accuracy of Wireless Fix due to third D.F.*

W/T DIRECTION FINDING

No.	Country.	W/T Station.	Call Signal.	Latitude N. ° ′ ″	Longitude W. ° ′ ″	Wave Length (metres).	Range (miles.)
6070	UNITED STATES (Atlantic and Gulf Coasts)	Bar Harbour, Me.	NBD	44 18 36	68 11 27	800	
6071		Gloucester, Mass.	NAD	42 35 19	70 41 08	800	
6072		Deer Island, Mass.	NAD	42 21 15	70 57 30	800	
6073							
6074		Cape Cod, Mass.	NAE	42 02 58	70 04 32	800	
6075		Surfside, Nantucket, Mass.	NBS	41 14 42	70 05 56	800	
6076							
6077		Price's Neck, R.I.	NAF	41 27 06	71 20 15	800	
6078		†Watch Hill, R.I.	NAF	41 18 21	71 51 29	800	
6079		Montauk, L.I.	NAH	41 03 09	71 57 27	800	
6080							
6081		Fire Island, N.Y.	NAH	40 38 07	73 12 32	800	
6082							
6083		Sandy Hook, N.J.	NAH	40 28 12	74 01 06	800	
6084		Mantoloking, N.J.	NAH	40 01 30	74 03 10	800	
6085							
6086		Cape May, N.J.	NSD	38 56 41	74 53 10	800	
6087							
6088		Bethany Beach, Del.	NSD	38 32 45	75 03 21	800	
6089							
6090		Hog Island, Va.	NCZ	37 22 36	75 42 37	800	
6091		Cape Henry, Va.	NCZ	36 55 16	75 59 51	800	
6092		Cape Hatteras, N.C.	NDW	35 14 22	75 31 42	800	
6093		Cape Lookout, N.C.	NAN	34 36 13	76 32 15	800	
6094		North Island, S.C.	NZW	33 13 21	79 11 06	800	
6095		Morris Island, S.C.	NAO	32 41 36	79 53 17	800	
6096		*Pass à Loutre, La.	NBX	29 11 24	89 02 26	800	
6097		*Burwood, La.	NBX	28 57 27	89 23 10	800	
6098		*Grand I., La.	NLI	29 13 52	89 59 46	800	
6099							

* Limited service. † Temporarily out of commission.

STATIONS THROUGHOUT THE WORLD

ADDITIONAL DETAILS.

U.S. Naval D.F. stations operating for the purpose of furnishing bearings in the Western Atlantic and the Gulf of Mexico.

The primary object of these stations is to assist in the navigation of vessels during atmosphere of low visibility.

Where two or more D.F. stations have the same call signal it indicates that they are connected by telegraph to and under the control of a central control station, the call signal being the call of the central control station. When a request for bearings is made, the central control station invariably answers with a bearing from each of the D.F. stations under its control.

The following signals have been authorised and will be used until further notice :—

Signal.	Meaning.
QTE ?	.... What is my true bearing ?
QTE	.... Your true bearing is —— degrees from —— D.F. station.

To obtain bearings the D.F. station should be called on 800 metres in the usual manner, and the call followed by the signal " QTE ? " meaning " What is my true bearing ? " When told by the D.F. station to " K " (go ahead), the ship's operator should follow the procedure outlined below :—

(*a*) Transmit the ship's call signal for 30 seconds.

(*b*) Make dashes, each dash 5 seconds long, for one minute, with the ship's call signal after each dash.

(*c*) Terminate with the signal " K " (go ahead).

If satisfactory bearings are obtained, the operator at the D.F. station will call the vessel in the usual manner and reply " QTE," followed by the true bearing in degrees (0 to 359) spelled out in words, and the name of the D.F. station from which the bearing was obtained ; otherwise a repetition of the test will be requested.

The ship's operator should acknowledge receipt of the bearings by answering the D.F. station in the usual manner and repeat, in numerals, the bearings received. This procedure enables all stations concerned to check the bearings.

The following information is furnished by the Director of the U.S. Naval Communication Service : " The reliance that can be placed in bearings furnished by shore D.F. stations will be governed by the following conditions :—

(*a*) When two sets of bearings are received which do not agree, a third set should immediately be requested.

(*b*) In thick weather, bearings should be requested at least every half-hour.

(*c*) Bearings that pass over intervening land or that are tangent to the shore line are not as reliable as those that have a clear sweep over the sea.

(*d*) Navigators receiving a set of bearings should immediately investigate the approximate fix indicated and determine whether or not they are being furnished with bearings from the stations that should be most reliable.

(*e*) When the position of the ship as indicated by the D.F. bearing differs materially from the position by dead reckoning, a second set of D.F. bearings should be requested in order to check the first D.F. position."

NOTE.—While the U.S. Navy Department states that at the present time D.F. bearings have reached a high degree of accuracy, it must be understood that the U.S. Government incur no liability for any consequences resulting from any inaccuracy in the taking or transmission of D.F. bearings. These bearings are provided free of charge, as aids to navigation, to be used at the discretion of the master of the vessel.

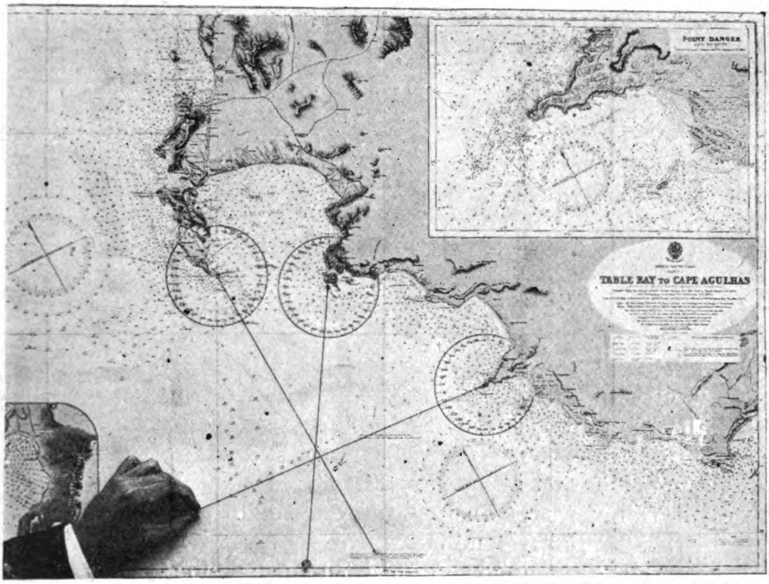
W/T DIRECTION FINDING STATIONS THROUGHOUT THE WORLD

No.	Country.	W/T Station.	Call Signal.	Latitude N. ° ′ ″	Longitude W. ° ′ ″	Wave Length (metres).	Range (miles).
6100	UNITED STATES (Pacific Coast)	Slip Point, Wash.					
6101		Empire, Oreg.					
6102		Fort Stevens, Oreg.					
6103		Westport, Wash.					
6104		Tatoosh I., Wash.					
6105		New Dungeness, Wash.					
6106		Cattle Point, Wash.					
6107		Smith I., Wash.					
6108		Eureka, Calif.	NPW	40 41 47	124 16 29	800	
6109	San Francisco entrance.	Point Reyes, Calif.	NLG	38 02 31	122 59 30	800	
6110		Bird I., Calif.	NLD	37 49 24	122 32 14	800	
6111		Point Montara, Calif.	NLH	37 32 04	122 31 06	800	
6112		Farallon, I., Calif.	NPI	37 42 00	123 00 00	800	
6113		Point Hueneme, Calif.					
6114		Point Arguello, Calif.					
6115		Point Fermin, San Pedro, Calif.					
6116		Avalon, Catalina I., Calif.					
6117		Point Loma, Calif.					
6118		Imperial Beach, San Diego, Calif.					
6119 to 6129							

These four stations will be under the control of Farallon I. W-T D.F. station, but for the present will continue to handle bearings independently as well as a co-ordinated group. Masters of ships are informed that in making use of the San Francisco harbour entrance group they are requested to call NPI, who will obtain bearings from the remaining stations in the group and furnish them to the ship, after corrections have been applied.

Otherwise the regulations for obtaining bearings are the same as on page 322 (*q.v.*).

Laying off Position Lines. (The "Cocked Hat.") When three D.F. stations are operating on an area and the series of bearings have been received at the control station, it will frequently be found, on laying off the position lines on the chart, that they do not intersect at one point but form a



Fig, 102. *A Method of plotting, at the Control Station, a Wireless Fix rom three D.F. stations.*

small triangle as shown in Fig. 102. This may be due to various causes as follows :—

(1) Carelessness in taking bearings. (Page 239.)

(2) Errors inherent in apparatus. (Page 318.)

(3) Night effect or coast refraction. (Page 161.)

(4) Discrepancy between great circle and rhumb line bearings when using Mercator's chart. (Page 113.)

(5) Bearings not taken simultaneously by all stations owing to misunderstanding and the ship having covered a considerable distance in the interim.

The triangle thus formed is referred to as a "cocked hat," and it is usual, unless the cause is known and can be allowed for, to assume that the position of the ship is at the centre of the triangular area.

A very rapid method of obtaining a fix at the control station is by having a large scale map on which each D.F. station is shown and has, in addition, its own protractor drawn round it. At the position of each station a pin is inserted, to which is attached a length of black thread and at the extremity of which is a push-pin of the pattern used for photography.

Directly the bearing of the ship is taken at the control station, it is recorded on the map by means of the thread which is held in position by the pins at either end, and as the bearings taken by the other stations are received at the control, they are also plotted in a similar way. The common intersection—or the centre of the " cocked hat," as the case may be, is then read off, logged and transmitted to the ship, and it may be also recorded on the map, if required for future reference, or in order to see at a glance the course which is being taken by the ship or aircraft.

This method of laying off position lines, in addition to being very rapid, does not result in the map becoming covered with pencil lines.

Fig. 102 shows the process being carried out, using an Admiralty chart.* It has been supposed, as an example, that D.F. stations have been erected at Cape Point, Cape Hangklip and Danger Point, and that a fix is being plotted at the control station. At the instant represented in the photograph, the bearings found by the first two D.F. stations have been laid off and the " Danger Point " thread is being adjusted to the angle reported by that station, the intersection resulting in a " cocked hat."

For the sake of clearness in the illustration, the protractors have been drawn comparatively small, but in practice it is usual to make them as large as the map will allow, or even to put suitable scales along the margin of the chart, thus adding considerably to the accuracy with which the thread may be manipulated. In such cases, the scales of the various stations may be drawn in different colours in order to avoid confusion where the scales intersect or overlap one another.

Practical Use of Charts on Shore D.F. Stations. The type of chart used on any shore station will depend largely on the conditions under which the station is working. If the station is for accurate observations of an experimental nature, a special gnomonic chart will probably be employed which has

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* Chart No. 2082 is here reproduced by kind permission of the Lords Commissioners of the Admiralty, Whitehall, London.

its point of contact at the station. Such a chart would not be possible in the case of a number of associated D.F. stations, as in cases 3 and 4 above, since the point of contact could not be at all the stations. Actually, it is possible to draw a chart which gives correct azimuths from two points, but only in rare cases would such a chart be considered worth constructing, and the case of three or four D.F. stations is ruled out. Here, if greater accuracy is desired than could be obtained with the Mercator's chart, a gnomonic chart would be chosen which had its point of contact as near to all the stations as possible.

A common use of the gnomonic graticule is in taking check bearings during the calibration of a shore station. The bearings are required to be known with as much accuracy as possible and yet, owing to the large number of transmitting stations within range—any of which may or may not be transmitting when required—it would be a tedious task to calculate all the great circle bearings. This is particularly the case when the D.F. station is a temporary one. In the case of a permanent station, the bearings of all transmitting stations in range should always be known accurately, and after the station is opened and working, will serve as a useful check on the presence of "night effect" and other freak conditions (Chapter 6).

PRACTICAL EXAMPLES OF THE USE OF GNOMONIC AND MERCATOR'S CHARTS IN THE CALIBRATION OF A D.F. STATION.

Suppose that it had been decided to erect a D.F. station in the neighbourhood of the Hook of Holland for the purpose of aiding the navigation of ships or aircraft crossing the North Sea. A suitable site having been chosen, the position of which is, say, lat. 52° N. long. 4° 08′ E., the station is erected and the apparatus installed, and it is then desired to take check bearings on transmitting stations in as many directions as possible for the purpose of calibrating the station.

A glance at a wireless map of Europe will show that there are a very large number of transmitting stations available for checking purposes within range of a D.F. station in Holland, and the simplest method of finding the true bearings of all these stations would be by means of a gnomonic graticule, which will enable the observed and true bearings to be compared in a fraction of the time taken to calculate the true bearings.

Choice of Gnomonic Chart (Graticule). Bearing in mind that the latitude of the D.F. station should correspond as closely as possible with that of the point of contact of the chart, we see that chart F of the 25 miles to the inch series (page 107) will meet the case. This chart, which extends from lat. 47° 30′ to 62° 30′ N., includes about 26 degrees of longitude and has its point of contact in latitude 55° N., which is within 3° of the D.F. station site.

Locating the D.F. and Transmitting Stations on the Chart. The charts as supplied have the parallels of latitude numbered off, but the meridians are left blank (page 106) and the meridian of the point of contact should be given the value of the meridian nearest to the D.F. station. In this case the longitude of the D.F. is 4° 08′ E. and so the centre meridian of the chart is called '4° E.' and the remainder numbered off accordingly, as shown in Fig. 103. (The charts when used in

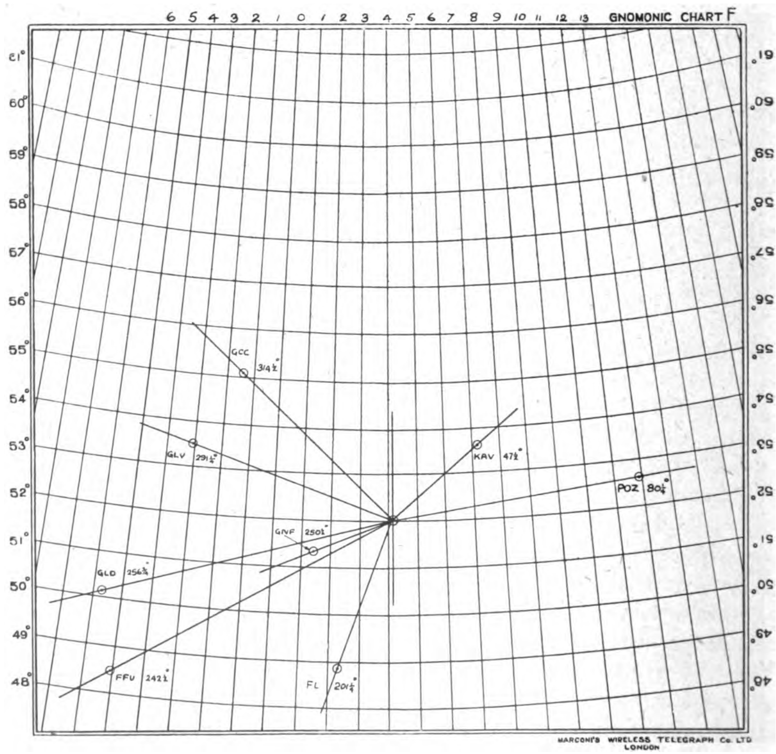


Fig. **103.** *Use of the Gnomonic Graticule in obtaining true bearings of Transmitting Stations from a D.F.*

the northern hemisphere should have the parallels of latitude concave upwards.)

Having numbered off the meridians, the positions of the D.F. station and transmitting stations in range are carefully plotted, each station being marked by a dot with a small circle round it and the call sign marked alongside. The size of the circles and thickness of the lines have been exaggerated in the figure, but these should be as light as possible. Lines are next drawn through the D.F. station and each transmitting station in turn, and a line is also drawn through the D.F. station parallel to the nearest meridian on the chart, to represent the direction of North. The bearings of the transmitting stations can now be scaled off with a protractor, which should preferably be of transparent material and at least 8 inches in diameter. It will make it more easy to ensure that the protractor is accurately registered with the 0°-180° line along the meridian, if the line representing the meridian be drawn so as to project some distance north and south of the position of the station.

Lines have been drawn through a number of stations in the figure and their bearings have been noted; actually, the number of stations heard on short and medium wavelengths would be well over a hundred.

The Use of the Mercator's Chart in the Above Example. The limitations of the Mercator's chart for D.F. work have already been discussed on page 114, but occasions may arise when use has to be made of such a chart in order to find the great circle bearings of transmitting stations for calibrating purposes. For distances between the D.F. and transmitting stations greater than 1,200 miles (see page 115) it is preferable to calculate the bearing in every case if accuracy is desired, but for shorter distances than this, the Mercator's chart may be used and correction for half-convergency applied to the bearings so obtained.

Fig. 104 shows a sketch map of England and Holland on the Mercator's projection, and we will suppose that it is desired to find what the bearing of Seaforth W-T Station (GLV) ought to be at the D.F. station in Holland, previously mentioned. The position of GLV is given as lat. 53° 28′ 14″ N. long. 3° 00′ 42″ W., and having fixed this point and that of the D.F. station, a line is drawn between the two with a straight-edge. The rhumb line bearing of GLV at the D.F. is then measured

with a protractor and found to be 288° 50′, to which must be applied the half-convergency.

$$\text{Diff. long.} = 3^\circ\ 01' + 4^\circ\ 08' = 7^\circ\ 9'$$

$$\text{Mid lat.} = \frac{53^\circ\ 28' + 52^\circ}{2} = \frac{105^\circ\ 28'}{2} = 52^\circ\ 44'$$

and from the H.-C. diagram, the half-convergency = 2° 50′.

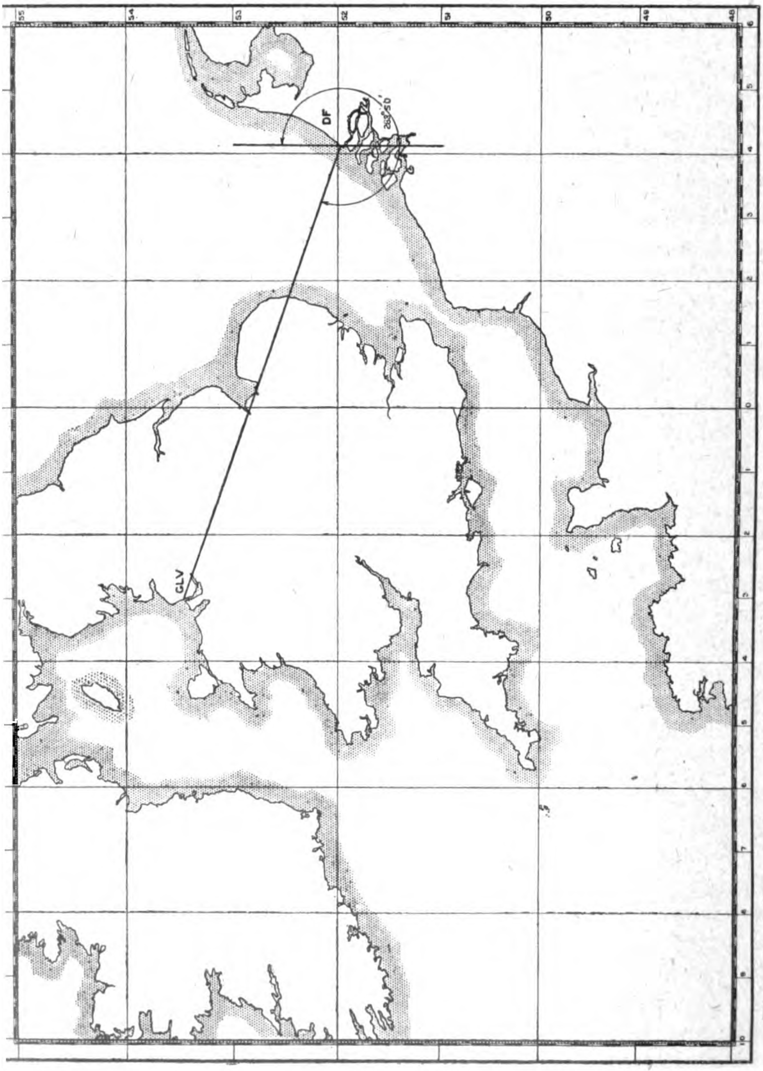


Fig. 104. *Use of Mercator's Chart in obtaining true bearing of a Transmitting Station from a D.F.*

Since the mid. lat. is north and the distant station is west of the D.F., the correction must be *added*, so that the great circle bearing of Seaforth is 288° 50′ + 2° 50′ = 291° 40′.

Discrepancies in Calculated and Measured Bearings. The bearings as found by either of the above chart methods do not differ from the calculated bearings by more than a small amount, which usually is well within the limits of experimental error and may be neglected. Thus, comparing the eight values obtained from the gnomonic chart in Fig. 103 with the calculated values, the maximum error is found to be only a third of a degree, whilst the mean error is less than a quarter of a degree. The corrected Mercatorial bearing of Seaforth, for instance, which was found above to be 291° 40′ differs from the calculated bearing (291° 35′) by five minutes only, which is negligible. (See page 343 for calculation.)

THE SHIP DIRECTION-FINDING STATION.

We shall now consider the far more flexible method of wireless navigation, which exists when the direction finder is installed in the ship. When such is the case, a position line can be obtained through any ordinary shore transmitting station, the position of which is known, or in other words, every such wireless transmitting station becomes a beacon. Greater precautions are necessary in the manipulation of a D.F. on board a ship, but the advantages to be gained and the rapidly increasing number of such installations make it essential to treat the subject in considerable detail. Particulars of a more practical nature concerning the way in which the aerials are rigged, the design of the receiving apparatus, etc., will be found in Chapter 8, but we may point out here one radical difference between the ship and shore methods.

In the case of the shore D.F. it was seen to be almost universal practice to calibrate the station in such a way that bearings of stations were read off as angles east of true North, a station due north of the D.F. being indicated at 0° on the scale of the radiogoniometer. On ship-board this is no longer possible, since the D.F. system is fixed relatively to the ship, which may be sailing on any course. It is standard practice, under these conditions, to calibrate the instrument so that 0° on the scale indicates the direction of a station dead ahead of the ship. Bearings are hence read off in a clockwise direction from the fore and aft line of the ship, and in order

to obtain the true bearing of a distant station, it is necessary, in addition to the D.F. bearing, to know also the course of the ship at the instant the bearing was taken, and it is the accurate and simultaneous reading of these two sets of bearings from a ship at sea which involve the "greater precautions" mentioned above.

The above situation may be illustrated as in Fig. 105, where O is a ship fitted with a D.F. and sailing on a course XY. A bearing by D.F. of a transmitting station P is found to be 40°, *i.e.*, 40° on the starboard bow, which, in itself, is of no

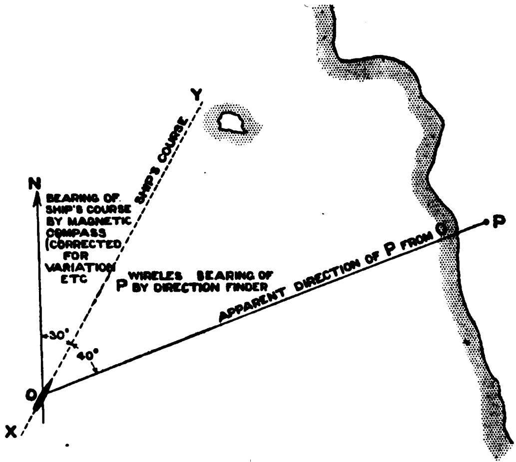


Fig. 105. *True bearing of Transmitting Station P from ship O is the sum of the bearing of the ship's course and the wireless bearing of P relative to the ship's course.*

particular value for the purpose of navigation, since there is not enough information to lay off a position line through P. If, however, at the instant of taking the D.F. bearing a reading had been taken of the magnetic compass and found—after being corrected for magnetic variation and deviation and converted to degrees (see page 288)—to give the ship's course as 30° east of North, then the true bearing of the station P from O would have been $30° + 40° = 70°$ east of North. Provided that the transmitting station is known to be not more than about 100 miles distant from the ship, this information is sufficient to enable a position line to be laid off forthwith on an ordinary nautical chart through the point P.

For long distance work, the discrepancy between rhumb line and great circle bearings introduces still greater difficulties than in the case of shore station working, and if a situation arises in which the distance of the station on which the bearing has been taken is not even approximately known, the only methods of obtaining a position line are by means of :—

(1) Mercator's chart provided with lines of bearing. (Page 116.)

(2) Retro-azimuthal chart. (Page 108.)

Neither of these charts are commonly to be found in a ship and they will not be considered further. In any case the position line would not be a reliable one, since the magnetic variation would not be known and the value chosen might be some degrees in error.

Position Line from Bearing of One Station. The situation mentioned above is unlikely to be met with in practice, as, even if the ship has been unable to take astronomical bearings for some time, there will be an "estimated position" from dead-reckoning, which will give the approximate magnetic variation and also enable the correction for convergency to be applied as described in Chapter 4, and a position line laid off *from* the transmitting station on a nautical chart.

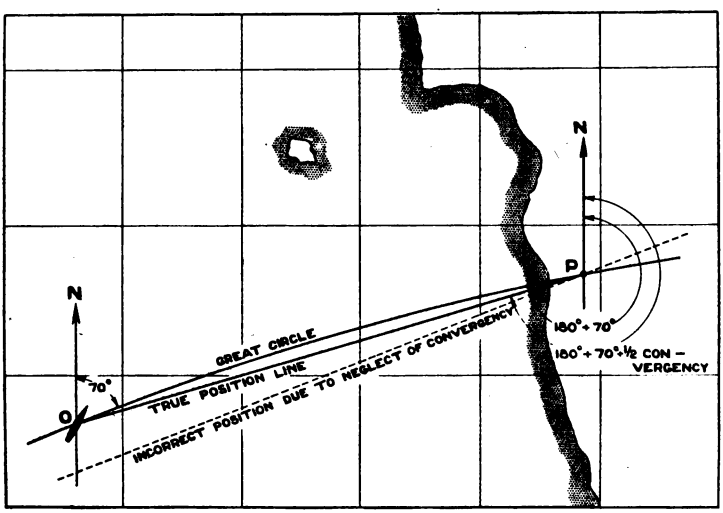


Fig. 106. *Position Line on Mercator's Chart from true bearing of one Transmitting Station.*

The estimated position of the ship will also give the approximate meridian, and thus enable a position line to be plotted on a gnomonic chart *from* the meridian of the ship *to* the station, thus avoiding the convergency error.

These operations are illustrated in Figs. 106 and 107, to which further reference will be made when considering cross-bearings from more than one station.

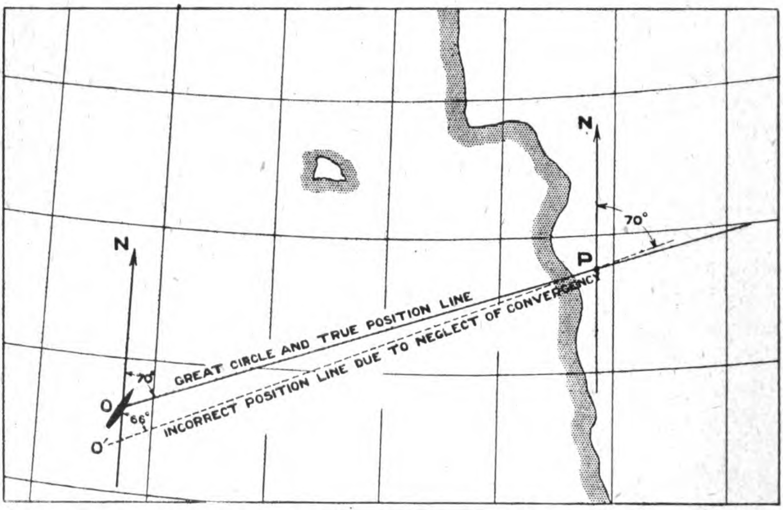


Fig. 107. *Position Line on Gnomonic Chart from true bearing of one Transmitting Station.*

Position Line from Bearings of Stations "In Transit." When a ship finds herself exactly in line with two transmitting stations, whether she be between the two stations or on an extension of the line joining them, the stations are said, as far as the ship is concerned, to be "in transit." This gives a position line immediately, as will be seen from the examples in Figs. 108 and 109. In the first case, the ship O, having attempted to take readings of the stations P and Q, finds that each of them bears 100°, and knowing the positions of the stations, the position line PQR is at once obtained. Similarly in Fig. 109, the bearing of P is found to be 100° and that of Q, 280°; that is to say, the signals arrive 180° apart on the scale of the D.F., indicating that the ship is on the line joining them.

On the nautical chart these position lines suffer from the same limitations as others and cannot be laid off accurately

when the distances involved are much greater than 100 miles, but since on the gnomonic chart all great circles are always

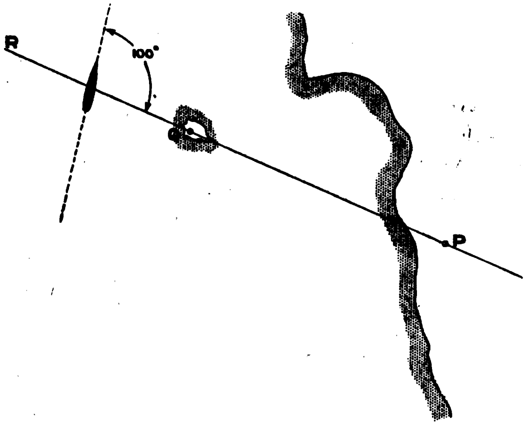


Fig. 108. *Position Line from Transmitting Stations "in transit."*

straight lines, the position lines may be drawn with accuracy to the limits of the chart. It is only the azimuthal properties that depend to some extent upon the relative positions of the stations and the point of contact.

It must not be anticipated that stations will be obtained "in transit" very frequently, for this necessitates that both stations must transmit within a few minutes of each other. However, occasions are met with in practice and it is then that a position line is provided which is independent of the corrections and approximations which have to be made when the magnetic compass is involved.

It should be mentioned that the trans-Atlantic flight provides an excellent opportunity for this method of navigating. Provided that the weather makes it possible for an aeroplane or airship fitted with a D.F. to take a direct route from America to Ireland, it would be possible to fly the whole way across whilst keeping to the great circle joining two high power stations on either side. Clifden, in Ireland, would be the nearest station on the

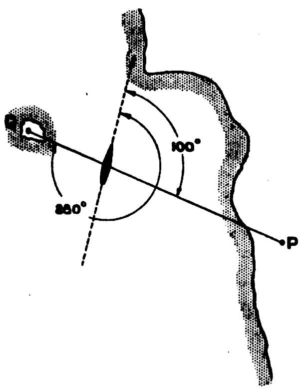


Fig. 109 *Alternative case o Position Line from Transmitting Stations "in transit."*

eastern side, and if, as in the first successful flight, the machine left from Newfoundland, there would be a number of stations to choose from in the west. The nearest of these would possibly be Glace Bay, in Nova Scotia, and would involve but a slight change of route in order

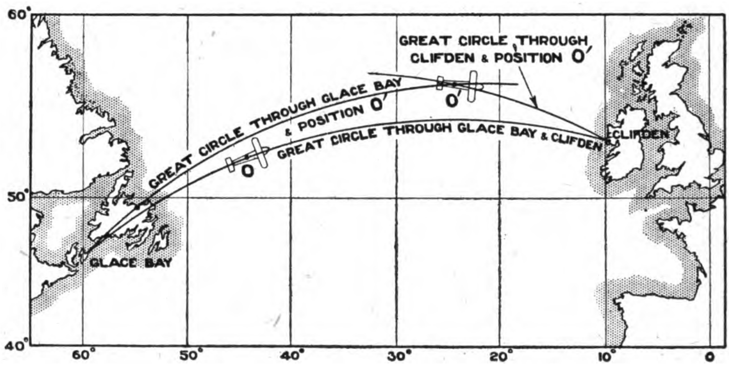


Fig. 110. *Suggested method of navigating Atlantic flight by transit bearings on Terminal Transmitting Stations.*

to follow the great circle between these stations. As shown in Fig. 110, it would then only be necessary to ensure that during the whole of the flight the signals from Glace Bay and Clifden were received at 180° and 0° respectively on the D.F., it having been previously calibrated to read 0°, dead ahead, as in the case of a ship. If, whilst the Glace Bay signals remained at 180°, Clifden were found at any time to bear 4°, it would indicate that the machine was to the north of the correct route as shown in an exaggerated degree in the figure, and the course would be altered until the signals were once again 180° apart on the scale.

In the presence of a strong beam wind, the readings would not be 0° and 180° owing to "drift," but they would still be 180° apart.

Fix by Cross Bearings on Two Stations. We have seen that unless the position of a ship is approximately known it is impossible to lay off an accurate position line by means of a single bearing on a transmitting station, except in certain circumstances. If a second or "cross bearing" can be obtained, both position lines can be drawn and the position of the ship thereby fixed.

In Fig. 111, suppose that a ship O takes bearings on the stations Q and P and finds them (after correcting) to be 30°

and 80° respectively. Then, knowing the positions of Q and P, it is required to reconstruct the state of affairs on a chart, not knowing the estimated position of the ship.

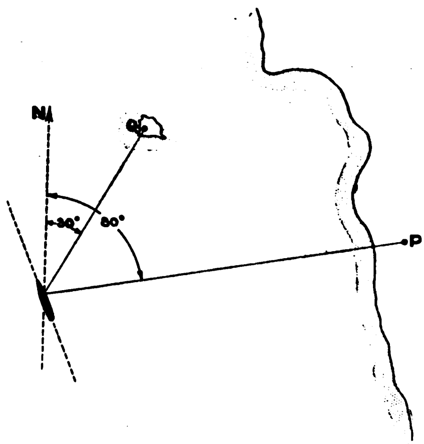


Fig. 111. *Fix by Cross Bearings, from Ship D.F., on two Transmitting Stations.*

Cross Bearings on Mercator's Chart. Suppose Fig. 112 to represent the above conditions on a nautical chart. The position of the ship is not known, but the true bearings, at a certain time, of the stations Q and P were 30° and 80° respectively, corrections having been made for magnetic variation and deviation, the former being only an approximate figure. Now it is impossible to get a fix by laying off the reciprocals of these bearings *from* Q and P since, although the bearing of Q from the ship is 30°, the bearing of the ship from Q is not 180° + 30° = 210°, but

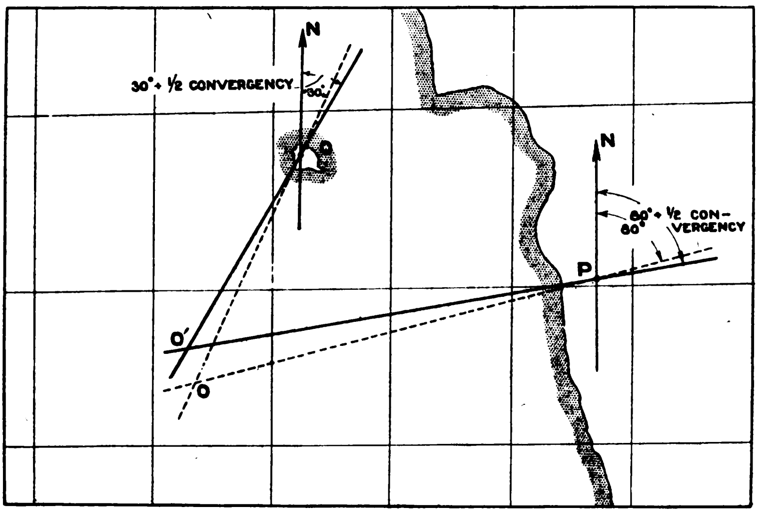


Fig 112. *Plotting Fix by Cross Bearings on Mercator's Chart.*

some other angle, depending on the relative disposition of the ship and the station Q.

If the approximate position were known, then the correction could be applied to the bearing, which would enable it to be laid off, and this indicates the method to be employed to obtain a fix. Lay off the bearings *from* the stations Q and P, as shown by the dotted lines in Fig. 112, and the intersection will give an approximate position for the ship at O. From this a check can be obtained on the value taken for the magnetic variation, which may affect the figure taken for the true bearing. It will also give a rough idea of the difference of longitude between the ship and Q, and also the middle latitude between the places, enabling the convergency correction to be worked out from the expression :—

$$\tfrac{1}{2} \text{ convergency} = \tfrac{1}{2} \text{ diff. long.} \times \sin \text{ mid. lat.}$$

Having made these adjustments to the original bearings, they can again be laid off from Q and P and a closer approximation to the true position is now obtained at O′. Since O′ and O do not coincide, it follows that further secondary corrections may have to be made to the magnetic variation, diff. long. and mid. lat. if anything approaching complete accuracy is desired, and having made these further adjustments, a third and still more accurate fix is obtained. This may be considered an unnecessary refinement which will rarely be employed, for even without it the laying off of cross bearings on a nautical chart is seen to be a tedious operation.

The Station Pointer. Instead of laying off the bearings on the chart in order to find the approximate position of the ship, a station pointer may be employed for the purpose and will give the same result, namely, at O. The corrections are then made to the bearings, the arms of the instrument adjusted accordingly, and the second fix O′ obtained and so on.

The disadvantage of using the nautical chart is the necessity of making a small calculation in connection with almost every long-range bearing before it can be applied to get a fix, and we will now investigate the use of the gnomonic chart in similar circumstances and see in what way the process is simplified.

Cross Bearings on the Gnomonic Chart. Fig. 113 shows an attempt to lay off the position lines on a gnomonic chart, the position of the ship being unknown, as before. If a

graticule is used, it will be assumed that a suitable one has been chosen for the latitude of Q and P. Since the degree of accuracy on a shore station cannot be obtained on a ship station, there is no great need to ensure that the estimated

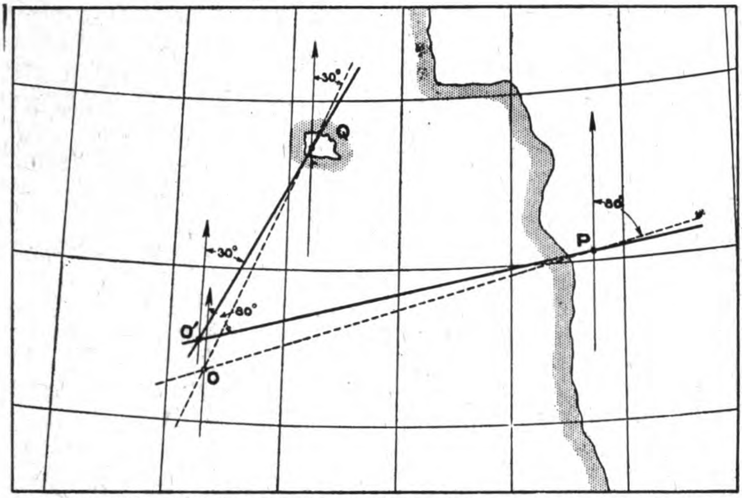


Fig. 113. *Plotting Fix by Cross Bearings on Gnomonic Chart.*

position of the ship should come very close to the point of contact of the chart. This may be considered if circumstances permit, or seem to warrant great care, but the errors produced by its non-observance have already been seen to be small (page 105).

As before, lay off *from* Q and P the bearings obtained from the ship. These will not be the true position lines, but will intersect at some point O and give an approximate position for the ship. This rough fix will give a check on the figure for the magnetic variation which was used to obtain the bearings, and they can be corrected in accordance with this if necessary. In addition to this, the meridian of the point O can be assumed to be the meridian of the ship when the bearings were taken, and the position lines may now be laid off *from* this meridian, through the respective stations, and a new point of intersection obtained. Fig. 107 illustrates the necessity for this. This second intersection O′ ought to come fairly near the meridian selected, and if it does not, the meridian of O′ should be taken, and, after making secondary adjustments to the bearings, they are laid off from the meridian of O′ and a third intersection obtained.

To get a fix by this method will be seen to be just as lengthy a process as with a nautical chart, but the use of the station pointer in this case simplifies the problem.

The Station Pointer. As before, the arms of the instrument are set to include respectively the true bearings of the stations P and Q from the ship. Since the gnomonic chart reproduces great circles as straight lines, and the great circle angles are correctly rendered, the state of affairs which existed at the instant the bearings were taken is reconstructed with a minimum expenditure of time and trouble. A pencil mark is made at the centre of the station pointer giving the fix. There still remains, however, the possibility of having to make a further correction in case the value taken for magnetic variation proves to be incorrect.

On page 153 will be found examples on the practical use of charts in navigation by cross bearings, using both nautical and gnomonic charts.

Fix by Cross Bearings of Three Stations. The remarks at the beginning of the chapter regarding the accuracy obtainable in wireless direction finding by means of shore stations (Figs. 100 and 101), apply with equal force when the D.F. is installed in a ship, and a cross bearing on a third shore station will materially improve the value of the fix. A " cocked hat " will frequently be produced by the intersection of the lines, owing to errors which have been detailed on page 131, and in connection with the last one mentioned, namely, that due to the time which elapses between the taking of the first and last bearing, the following is a method by which allowance may be made for the distance travelled by the ship in the interval.

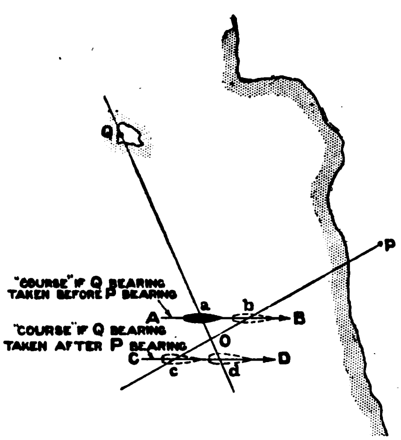


Fig. 114. *A Method of Plotting Fix when an interval of time elapses between taking cross bearings on two Transmitting Stations.*

Allowance for Distance Moved by Ship Whilst Taking Cross Bearings. In Fig. 114, suppose that the bearing of Q is obtained 15 minutes before that of P, during which time the ship was sailing on a course due east at 12 knots. Then

the distance travelled during the interval would be three miles, and the point O would not represent a position of the ship during that time. If we draw a line AB in a direction due east, and in such a position that the part *ab* intercepted by the position lines is a length equal to three miles—to the scale of the chart—then the points *a* and *b* were approximately the positions of the ship when the two bearings were taken. Had the bearing of P been taken first, then the line would have been drawn in the position CD to represent the course, and the positions *c* and *d* on the first and second position lines respectively would be the two positions required.

If a ship, whilst steaming, say, south-east at 12 knots, takes bearings on three stations P, Q and R, at intervals of 15 and 10 minutes respectively between bearings, then the results may be tabulated as follows:—

Station.	*Time.*	*Interval.*	*Distance.*
P	3 p.m.		
		15 min.	3 miles.
Q	3.15 p.m.		
		10 min.	2 miles.
R	3.25 p.m.		

In Fig. 115, the bearings of P, Q and R are shown plotted out, after having made all the necessary corrections and adjustments, and are seen to form a "cocked hat," the centre of which would normally be taken as a fix. From the above information, however, we are able to draw a line AB in a direction south-east on the chart to represent the course of

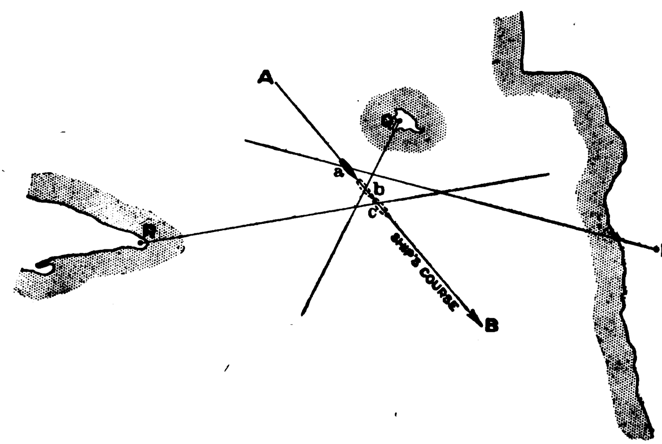


Fig. 115. *A Method of Plotting Fix when intervals of time elapse between taking cross bearings on three Transmitting Stations.*

the ship, and it is drawn in such a manner that it intersects the position lines from P, Q and R in the order in which the bearings were taken, and also such that the intercepts *ab* and *bc* are each proportional, as before, to the distances covered in the intervals between the bearings, namely, three miles and two miles. Then *a*, *b*, and *c* were the positions of the ship, none of which is seen to be near the centre of the "cocked hat," thereby showing the necessity for the correction.

In plotting the direction of the ship's course, due allowance must always be made for wind, tide and currents, and the compass reading alone must not be taken to represent the course.

The process can be carried out quite simply with a parallel rule and a pair of dividers, the scale of miles being measured from the nautical chart, as explained on page 110, or, if a gnomonic chart be in use, the scale—if not marked on the chart—can be obtained from the distance between the nearest pair of parallels of latitude, which is equal to 60 nautical miles.

Since the station pointer takes no account of the time which has elapsed between the taking of the various bearings, there are cases in which its use may result in an incorrect fix, and this point is dealt with on page 157, where an example is given of the method of obtaining a fix from a short-range station. In all such cases the distance travelled by the ship has an appreciable effect upon the fix. In cross bearings from long-range stations, unless the bearings are taken at very long intervals, the effect may generally be neglected.

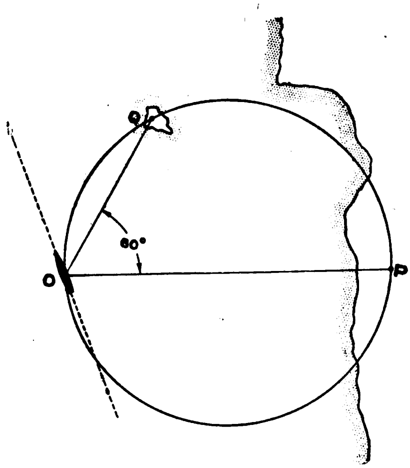


Fig. 116. *The Position Circle.*

Position Circle. Angle Subtended at Ship by Two Shore Stations. Suppose that the ship O in Fig. 116, instead of taking true bearings of P and Q, measures only the angle subtended by the stations, that is to say, the angle POQ. The necessity for

this might arise owing to the temporary unreliability of the magnetic compass, due to magnetic storms or possibly some accident.

Instead of fixing the position of the ship, this gives a **position circle,** as shown. Students of Euclid will recognise the conditions as those of a proposition which proves that in the arc AOB of any circle AOBC, as in Fig. 117, all the angles AOB, AO′B, AO″B, etc., are equal to one another. Similarly, all the angles on the other side of the chord AB, such as ACB, AC′B, etc., will be equal to one another, but will not be equal to AOB unless AB be a diameter of the circle.

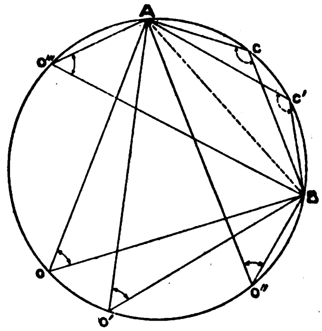


Fig. 117. *Geometry of the Position Circle.*

If, therefore, in Fig. 116 the angle subtended by P and Q be found to be 60°, then the ship must lie somewhere on the arc POQ of a circle of such a diameter that all angles POQ, PO′Q, etc., are equal to 60°. It at once becomes necessary to have a simple means of constructing this position circle. In Fig. 118, let P and Q again be the two points which subtend an angle of 60° at all points on the required circle. To find the centre of the circle, join PQ and bisect the line at right angles at V by the line SVT. At Q draw a line QC, cutting ST at C, and such that the angle VQC = 90° − 60° = 30°. Then C will be the required centre and the position circle may be described with radius CQ.

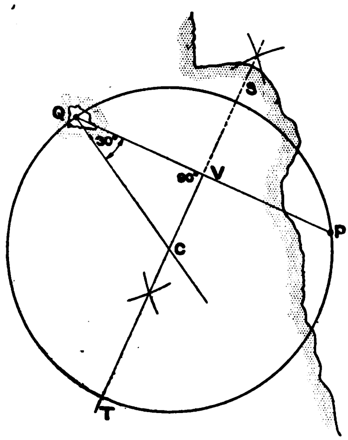


Fig. 118. *Construction for finding Centre of a Position Circle.*

Intersecting Position Circles. Angles Subtended at Ship by Three Shore Stations. If, as in Fig. 119, a third station be available and the angle QOR is measured by the D.F. to be 100°, then in the same way as before, a

second position circle can be drawn for the stations Q and R. Now, the position of the ship must lie on both these circles, and therefore, as in the case of position lines, it will be at the intersection O, the other intersection being the common station Q.

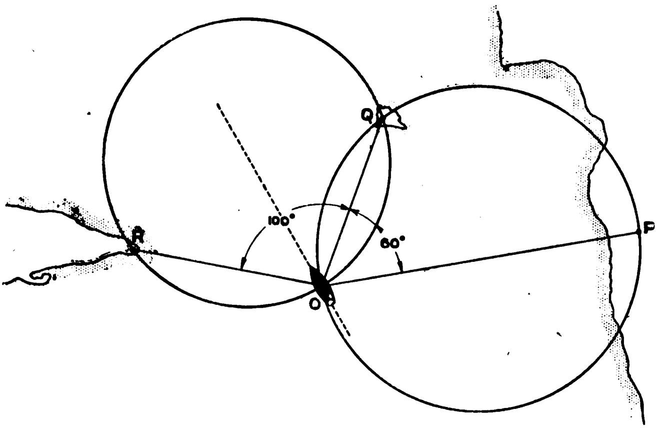


Fig. 119. *Intersecting Position Circles.*

In the case of bearings on three stations, the station pointer is particularly useful, and it was, indeed, in connection with the " horizontal sextant angles " of ordinary navigation that the instrument was first developed. This type of fix, being quite independent of the magnetic compass, is about the most rapid and accurate one which can be got ; but the accuracy largely depends upon the relative disposition of the stations and the ship, and is particularly unreliable when the position of the ship is anywhere near the circumference of the circle drawn through the three stations. This point is discussed below.

Special Case when Position Circles Coincide. If the ship O in Fig. 120 is in such a position that the two position circles PQO and RQO coincide, then it will not be possible to obtain a fix from observations of subtended angles alone. For instance, suppose that at a certain time the angles POQ and POR are found to be 25° and 128° respectively, and that an attempt be made to fix the ship's position by means of a station pointer, it will be found impossible to do so, since the conditions are satisfied at any point of the circle ROQP for reasons already stated. In such a case, the only method

of getting a purely wireless fix is by taking the true bearings of one or more of the stations and plotting position lines to

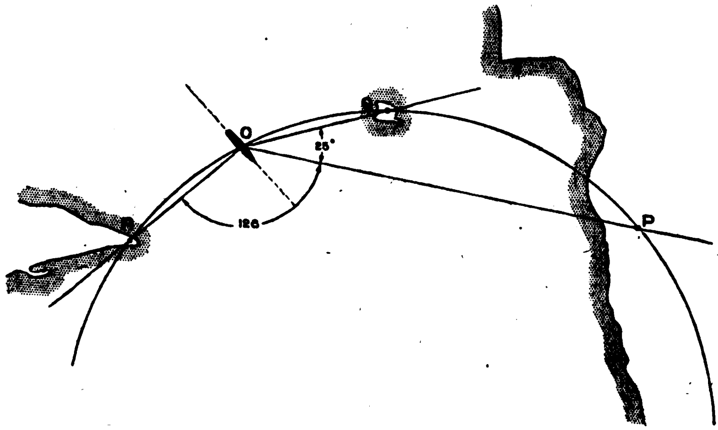


Fig. 120. *Coincident Position Circles.*

intersect this circle, or by waiting until the ship has proceeded on her course for some time, and the position circles are no longer coincident.

Running Fix by Bearings on a Single Station. This is a method of fixing the position of the ship from bearings on a single station and is of particular use when coasting. Suppose that in Fig. 121 the ship takes a bearing on the shore station P and finds it to be 60°. This position line is laid off on the chart from P in the direction PS and is called the "First Position Line." This is essentially a case for the employment of the nautical chart, since the method is almost useless at great distances from the transmitting station, owing to the time taken to obtain a result. At the instant of taking the first bearing, the patent log is read and a record is kept of the course of

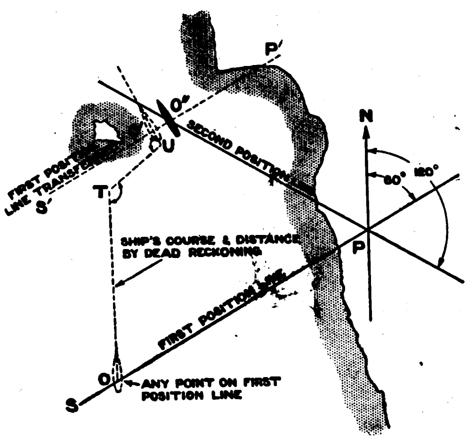


Fig. 121. *The Running Fix.*

the ship and the distance run on each course if the course be changed. As soon as the bearing of P has appreciably altered (the change should be at least 30°, and is shown as 60° in Fig. 121), another bearing is taken, and the patent log again noted. The method of fixing the position of the ship is then as follows.

It is known that when the first bearing was taken the ship was somewhere on the line PS. Choose any point O and let this be supposed to be the position. Now, from O lay off the course and distance of the ship up to the time of taking the second bearing, and suppose this to be represented in the figure by the line OTUO′. Through the point O′, draw a line P′O′S′ parallel to the first position line. The ship must have been somewhere on this line at the time the second bearing was taken, whether the point O was chosen correctly or not, since, wherever O be chosen, laying off the course and distance would have resulted in the same line P′O′S′. This latter line is called the "First Position Line Transferred."

If, now, the second bearing be laid off from P, which we will assume was 120°, it will cut the line P′O′S′ at some point O″, which was the ship's position at the instant of taking the second bearing.

Prevention of Collision. Whenever a ship (A), hears wireless signals from another ship (B), during fog, and the bearing of B is found to be on the *bow*, a watch should be kept to make sure that the condition of *constant bearing and increasing signal strength* does not exist. Under these circumstances there is a grave chance of collision, and the position becomes more serious if the bearing be on the starboard bow, as in this case it is the duty of A to keep clear.

By keeping watch on the bearings it is possible to detect whether the ship is drawing ahead or astern, and in case of any doubt, a call can be given to find out the course of the ship.

It should be remembered that when a ship is a considerable distance, the bearing will appear to remain constant for long periods, and some effort should be made on the part of the telegraphist to estimate the probable distance, from the strength of signals—which should be quite a feasible thing after a certain amount of practice and familiarity with the receiver, which he is using.

Vessels in Distress. In the case of a distress call, when the vessel concerned sends her position, it is preferable to

attempt to find her by keeping her at 0° on the scale of the D.F. and ignoring the position given. Cases have occurred in which the estimated position was given 100 miles in error, and as long as she is able to make signals with her wireless transmitting set, the above method affords the most rapid way of finding her.

EXAMPLES OF WIRELESS POSITION FINDING.

Example of a Fix by Cross Bearings on Long Distance Stations, using a Nautical Chart. In this example it is proposed to take the case of a ship which is to the north-west of Cape Finisterre, and is in estimated position 44° 0′ N. and 10° 0′ W. Position finding by means of cross bearings will be met with far more frequently than any other method, and since the ordinary nautical charts are available in the chart room of every ship, the above example has been taken as typical of a long range fix.

Suppose that the *actual* position of the ship at the time the wireless fix was obtained was 44° 30′ N. and 10° 40′ W., in which case the true bearings of three of the stations on which bearings were taken ***should be*** as follows :—

Crookhaven	4° 41′
Ushant	42° 11′
Aranjuez	128° 23′

This information regarding the actual position is of course not known to the ship, and the bearings as obtained by the direction finder will be assumed to have errors of approximately 1°. Bearing these facts in mind, we will examine the method of obtaining a fix and note to what extent it is affected by the errors in bearings and the distance over which they are taken.

Fig. 122 shows a sketch chart on which the above transmitting stations have been marked. On most nautical charts, shore wireless stations—or at any rate coastal stations—are shown, but the positions should always be checked from a list of stations, such as that in the *Year Book of Wireless Telegraphy and Telephony* or one of the official lists supplied to ships.

The conditions which have been chosen are particularly bad ones for obtaining a wireless fix by cross bearings in that, with the exception of Cape Finisterre, the transmitting stations are at greater distances from the ship than they should be for

accurate position finding. This has been done purposely, as it shows up the resulting errors more clearly. For this reason we shall assume that Finisterre was not working at the time, and that the bearings had to be taken on the remaining long distance stations.

We will suppose that bearings were taken first on Crookhaven and Ushant, and after being converted to true bearings, were as follows :—

Station.	Call Sign.	Latitude.	Longitude.	True Bearing.
Crookhaven	GXO	51° 27′ 00″ N.	9° 46′ 00″ W.	5°
Ushant	FFU	48° 27′ 05″ N.	5° 05′ 00″ W.	43°

From the estimated position of the ship and the values tabulated above for the positions of the stations, the necessary corrections for convergency are next found.

Ushant.	Long. of estimated position of ship	= 10° 00′
	Long. of **Ushant**	= 05° 05′
	Diff. Long.	= 04° 55′
	Lat. of estimated position of ship	= 44° 00′
	Lat. of **Ushant**	= 48° 27′
	Sum of Lat.	= 92° 27′

$$\text{Mid Lat.} \qquad \frac{92^\circ\ 27'}{2} = 46^\circ\ 14'$$

Half-convergency from diagram = 1° 45′.

Referring to Fig. 92, it is seen that the above corresponds with case (*b*), in which the mid. lat. is north and the transmitting station is east of the ship. Great circle bearings are being converted to rhumb line, and so the correction is a + ve, one which gives the rhumb line bearing of Ushant to be 43° + 1° 45′ = 44° 45′.

Since Crookhaven is almost due north of the ship, the diff. longitude only being a fraction of a degree, the correction for convergency may be neglected and the rhumb line and true bearings assumed to be the same. This is to be expected, since the meridians are themselves great circles, and hence any rhumb line which lies along or close to a meridian, will also closely approximate to a great circle.

The position lines are now plotted on the chart by laying off the reciprocals of the corrected Ushant bearing (44° 45′ + 180° = 224° 45′) *from* Ushant and of the Crookhaven bearing (5° + 180° = 185°) *from* Crookhaven, a fix being obtained at

10° 39′ W. and 44° 38′ N., but serious discrepancies will probably be present, owing to the magnified effect, at such great distances, of the errors which were assumed in the bearings. Over a distance of approximately 400 miles, an error in bearing of one degree will give a change in the position of the fix of about seven miles if the intersection of the position lines is at right angles, and considerably more if the intersection be acute.

Suppose that it had been possible to obtain a check bearing on Aranjuez within a short time of the other two bearings, which resulted as follows :—

STATION.	CALL SIGN.	LAT.	LONG.	TRUE BEARING.
Aranjuez	EAA	40° 01′ 48″	03° 40′ 32″	128°

The correction for convergency, obtained as in the case of Ushant, is 2° 06′, and is again a + ve correction as the conditions are the same as for Ushant, giving a corrected bearing of 128° + 2° 06′ = 130° 06′.

The reciprocal angle (130° + 180° = 310°) is now laid off *from* Aranjuez and the three position lines result in a "cocked hat," the centre of which is approximately at 44° 28′ N., 10° 43′ W., and this would be taken as the position of the ship. We see that the difference between the true position and the wireless fix is roughly five miles and errors of this order must be anticipated in similar cases.

It was assumed that Finisterre was not transmitting, but had it been possible to obtain a bearing on this station the resulting position line should be a very reliable one as the distance is so short. The assumption was made in order to show the unsatisfactory nature of

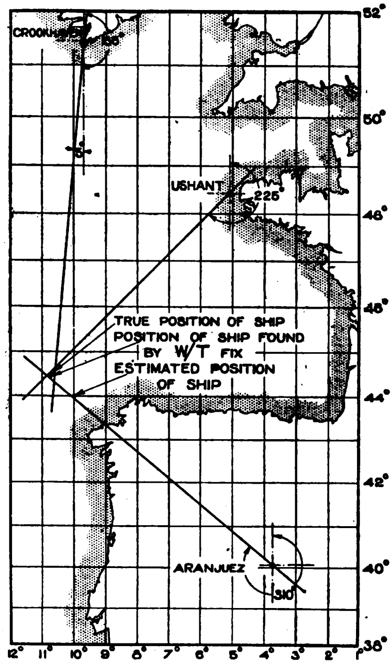


Fig. 122. *Long Range Wireless Fix using Mercator's Chart.*

the fix obtained from long distance stations unless only approximate accuracy is required.

Example of a Fix by Cross Bearings on Long Distance Stations, using a Gnomonic Chart. Consider, now, the use of the gnomonic graticule in connection with the previous case of a ship north-west of Finisterre which has obtained bearings on long distance stations as before. (See previous example.)

From the series of gnomonic charts carried in the ship, a suitable one is selected which will include the stations known to be in range at the time, and it will be found, for instance, that chart G of the 25 mile series (page 107) extends from lat. 37° 30′ N. to 52° 30′ N. and will meet the case. The method of locating the transmitting stations on the chart has already been described (page 134). There is, however, a difference between the two cases in that it is no longer always possible—nor even necessary—to ensure that the position of the ship coincides closely with the point of contact of the chart (see page 144). However, we are told that the estimated position of the ship at the time the bearings were taken was 44° 00′ N., 10° 00′ W., and the point of contact of this series of charts being at the centre of the sheet we can call the centre meridian 10° W. and number the remainder off accordingly.

Fig. 123 shows the chart with the stations marked in position.

The problem of fixing the position of the ship from the information obtained lends itself so readily to the use of the station pointer that it would seem hardly worth while discussing the method of laying off the position lines. Cases may arise, however, in which the instrument is not available, or it may be necessary to lay off the position lines in order to make allowance for the distance travelled by the ship.

The estimated position of the ship being near to the meridian 10° W., a point is found on this meridian such that a bearing from it through the position of Ushant is 43°, this being accomplished by means of a protractor, straight-edge and a certain amount of patience. Adjustable protractors are also procurable which have a straight-edge attached and reduce the time taken to plot the line. In a similar way the 5° bearing of Crookhaven and the 128° bearing of Aranjuez are

laid off from the 10° W. meridian and a "cocked hat" is again obtained, as shown in Fig. 123, from which the position of the ship is fixed in 44° 26′ N., 10° 46′ W.

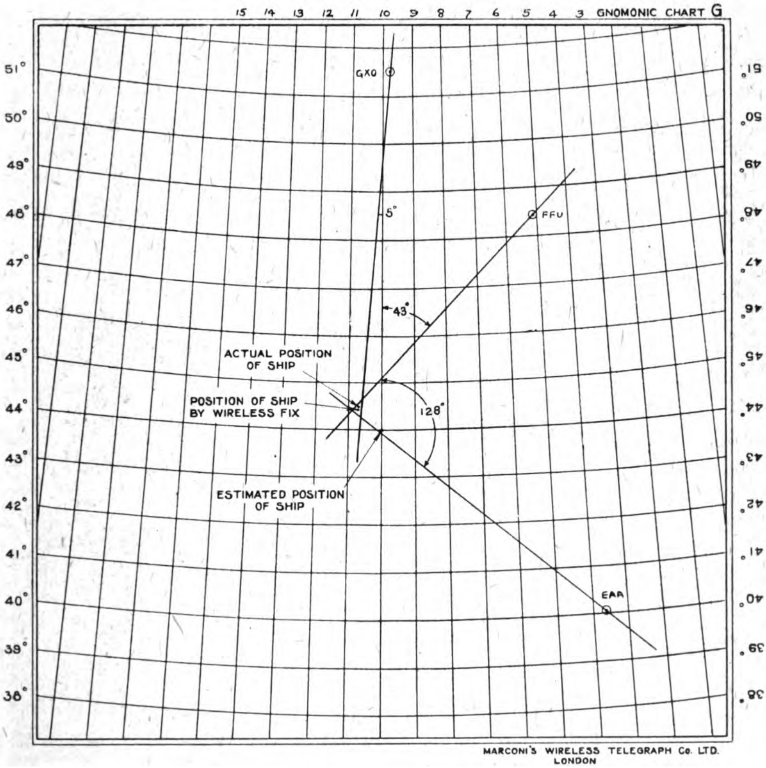


Fig. 123. *Long Range Wireless Fix using Gnomonic Graticule.*

Example of a Fix by Cross Bearings on Short Range Stations :—

(1) Allowing for the movement of the ship during process.

(2) Using station pointer.

(1) A ship in the English Channel in estimated position 49° 30′ N., 4° 30′ W., at 4.30 p.m,, is steaming at 15 knots on a course due east. Bearings are taken of various stations as they are heard from time to time, and the true bearings

are tabulated below, together with the times at which they were obtained.

TIME P.M.	STATION.	CALL SIGN.	LATITUDE.	LONGITUDE.	TRUE BEARING.
4.35	Niton	GNI	50° 34′ 33″ N.	1° 17′ 55″ W.	62°
4.55	Ushant	FFU	48° 27′ 05″ N.	5° 05′ 00″ W.	208°
5.05	Land's End	GLD	50° 07′ 03″ N.	5° 40′ 10″ W.	300½°

Since none of these stations is more than 100 miles from the estimated position of the ship, the true bearings may be laid off from the stations on a nautical chart without correction, and in Fig. 124, which is drawn on Mercator's projector, they are seen to produce a "cocked hat" several square miles in area.

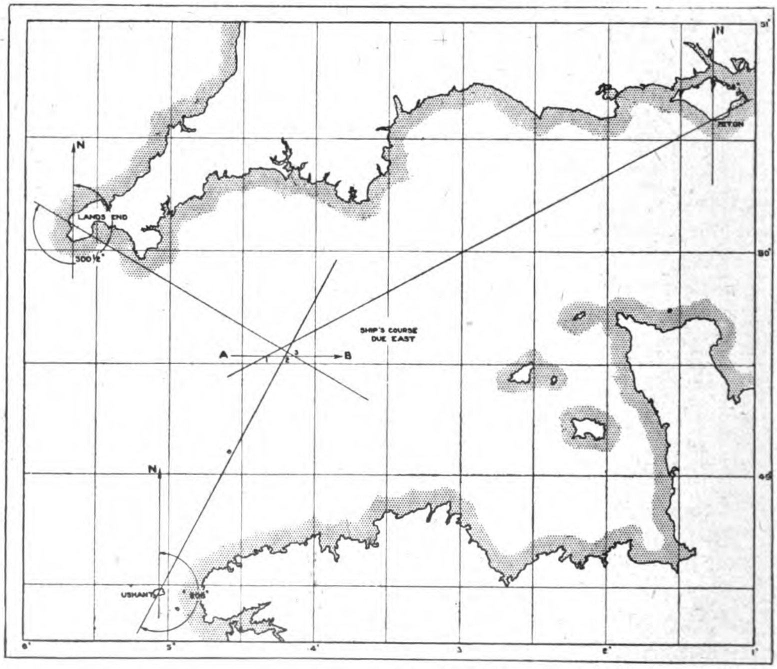


Fig. 124. *Short Range Wireless Fix when time elapses between taking Cross Bearings.*

Now, since the speed of the ship is 15 knots, the distance covered between taking the Niton and Ushant bearings is 5 miles, and between the Ushant and Land's End bearings, 2½ miles (taking no account of tide or currents). These distances are scaled off from the chart (in the way described on page 146), and marked on the edge of a sheet

of paper, this improvised scale being applied to the chart at the intersections of the position lines in such a way that the edge of the paper lies in a direction due east, corresponding to the course AB of the ship. It is then adjusted until the three points 1, 2 and 3 corresponding to the bearings on GNI, FFU and GLD lie on their respective position lines, taken in the correct sequence. In the figure they are shown as coinciding, but there will usually be difficulty in getting complete agreement, owing to small errors in taking the bearings.

The three positions are found, from the chart, to be :—

Time.	Latitude.	Longitude.
4.35 p.m.	49° 32′ N.	4° 20′ W.
4.55 p.m.	49° 32′ N.	4° 12½′ W.
5.05 p.m.	49° 32′ N.	4° 09′ W.

the latitude being constant in each case, owing to the course of the ship being east.

In estimating the course of the ship, due regard should be paid to the effects of tide and currents, etc., as well as merely the magnetic compass reading.

(2) **The Station Pointer.** Had the above readings been taken within a few minutes of each other (and the above intervals are longer than would usually be met in practice in such a busy wireless area as the English Channel), then the station pointer could have been employed. There are two ways in which the instrument may be used, the first being to make use of the true bearings of any two of the three stations, and the second is to use the subtended angles, at the ship, of all three stations. Thus, in the first case, the centre leg of the station pointer will represent North, the right leg will be set to 62° to represent the Niton position line and the left leg to 300½° for Land's End. The instrument is then laid on the chart with the centre leg parallel to a meridian and the adjustable legs are arranged to pass through the respective stations, giving a fix. The same process can then be carried out for another pair of stations and the results averaged.

In the second method, the direction of the meridian is ignored and the three legs are set so as to include angles equal to those subtended, at the ship, by the three stations. Thus, suppose the centre leg to represent the Land's End

position line, then the right leg will be set at $(360° - 300\frac{1}{2}°) + 62° = 121\frac{1}{2}°$ and the left leg at $(360° - 300\frac{1}{2}°) + 208° = 267\frac{1}{2}°$ for Ushant. The station pointer is then applied to the chart in the way shown in Fig. 125* so that the three legs

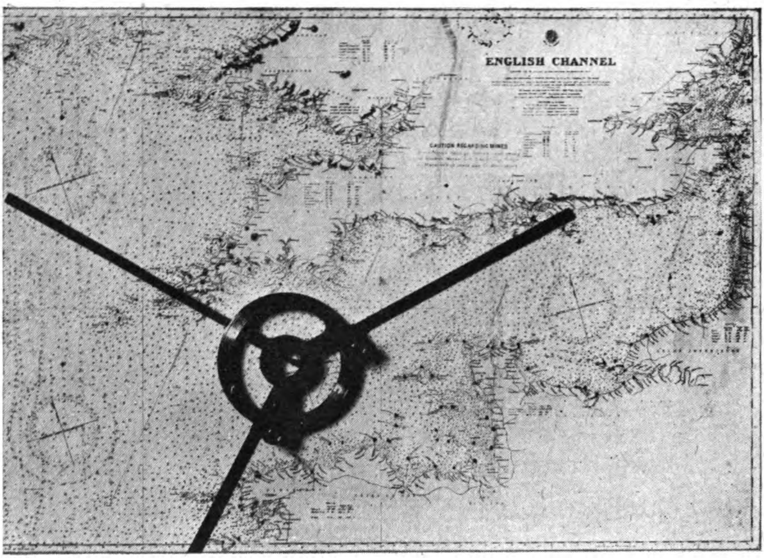


Fig. 125. *Wireless Fix by Cross Bearings using Station Pointer.*

pass through the respective stations and a fix is obtained which will coincide with the centre of the cocked hat of Fig. 124.

*Admiralty Chart No. 1598 is here reproduced by kind permission of the Lords Commissioners of the Admiralty, Whitehall, London.

CHAPTER 6.

NIGHT EFFECT AND OTHER FREAK PHENOMENA.

In Chapters 2, 7 and 8, a number of possible causes of error in observed bearings are mentioned, together with the corresponding methods which should be adopted to reduce them to within reasonable limits. The most important of these are as follows :—

Vertical and direct, both of which produce what may be called a dilution of the directive receiving property of the system, but which are nevertheless easy to detect and to eliminate.

Local screening and masses of conducting material near the aerial produce distortion of bearings, which is detected when checking the installation by means of bearings on distant stations or a portable transmitting station. Errors of this nature may often be reduced by the methods described on page 254, headed "Calibration."

In addition to these errors which are associated with the receiving system or the site of the station, there are a number of other factors which give rise to incorrect bearings, some of which are at present beyond our control to eliminate. The chief of these are :—

(1) **Coast Refraction**, or deviation of the direction of travel of the electro-magnetic wave on crossing obliquely a sudden change in the nature of the earth's surface.

(2) The series of phenomena to which has been given the name of "**Night Effect.**"

Coast Refraction. The effects of refraction in the case of light waves will be familiar to almost everyone. If a pencil be held so that a part of it is beneath the surface of some water, then, from most viewpoints, the pencil will have the appearance of being bent at the point where it enters the water. The effect is due to the fact that light travels more slowly in water than in air, and when the rays of light, reflected from the pencil, leave the water, the change in velocity results in a change in the direction of the rays. We may be excused for including at this point, an elementary

analogy of the process of refraction which, however, explains the effect very clearly.

Suppose a number of men to be marching in line in the direction of the arrow P in Fig. 126, on the smooth ground and with a speed of, say, four miles per hour. The line XY represents the boundary between the smooth ground and an area where marching is difficult and over which the speed falls to three miles per hour.

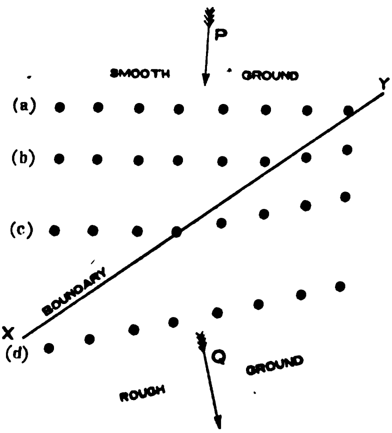


Fig. 126. *Analogy illustrating Refraction.*

When the line of men reach the position (b), those who have crossed the boundary are seen to be falling behind owing to their reduced speed. At (c) the effect is more noticeable still, and at (d) the whole line are now marching at the reduced speed, and a permanent deviation in the front has taken place.

Such a deflection from the normal direction of travel is almost exactly analogous to refraction, and it is clear that the effect is produced by a change in velocity at the boundary of the two media. In the special case when the line XY is parallel to the line of men who are marching, then no refraction effect is noticed, since all the men cross the boundary simultaneously.

So far as the refraction of light is concerned, the whole subject is well known and amenable to mathematical and experimental proof, a very simple relation existing between the angle of deviation of the light ray and the ratio of the two velocities in the different media on either side of the boundary surface.

It might not be anticipated, on first thoughts, that any such effect would exist in the case of electro-magnetic waves, since they are usually considered to be propagated through the ether and over the surface of the earth, so that the change in the nature of the earth's surface would not have any material effect. Both light and wireless waves are, however, propagated in the ether, and in both cases it is a secondary effect, such as

absorption, which causes the change in velocity. In the case of light, we know, further, that lights of different colours—that is to say, different frequencies—undergo refraction to varying extents, and it is owing to this fact that it is possible, by means of a glass prism, to split white light up into the spectrum colours.

A considerable amount of theoretical work has been done to determine to what extent electro-magnetic waves propagated over the earth's surface should be susceptible to refraction, and there is now abundant experimental proof of the theoretical results which were arrived at. Consistent deviations of from 4° to 5° have been noticed in the case of waves which cross the seashore at an acute angle, and, just as in the case with light, the amount of refraction is found to vary greatly with the wavelength when the latter is small, although above 2,000 metres the refraction seems to be almost independent of the wavelength. (76.)

Without going into details of the exact physical cause of the change in velocity of the electro-magnetic wave when it is trailing over different types of soil or over water, we may note that both experimental and also mathematical analysis indicate that the velocity over sea is from 2% to 5% greater than that over land.

Fig. 127 illustrates a practical case of coast refraction and its effect at a shore direction-finding station R, on the observed bearing of a ship at T. The direct path from T to R is the line TPR, but owing to refraction, the wave front is deflected at the coast, with the result that the actual ray which reaches the frame aerial has travelled by the path TP_1R, making the apparent bearing 5° too great.

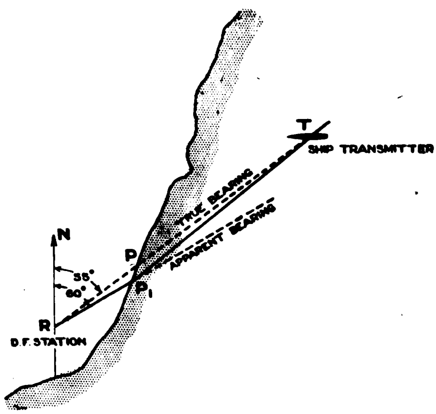


Fig. 127. *Effects of Coast Refraction.*

These effects can sometimes be allowed for, but whenever possible, sites at which such conditions are found to exist should be avoided.

NIGHT EFFECT.

The series of phenomena to which the above name has been given constitutes one of the most important subjects for research in wireless direction finding at the present time. As the name implies, the effects are only prevalent during the dark hours, but the resulting errors in bearings, as measured by a simple frame (or its equivalent) are frequently of such magnitude as to render D.F. work impracticable.

It has been noticed, since the early days of directive reception, that the minimum points sometimes became indefinite at night, making the operation of obtaining accurate bearings very difficult. A further effect, which was noticed was that the bearings of known transmitting stations were often unmistakably wrong, and that the errors might be several degrees in extent (19) (67). This trouble has remained a problem right up to the present time, and although methods of greatly reducing, or in some cases totally eliminating the effect seem to be within sight, all commercial direction-finding stations, when night effects prevail, make a point of either ceasing work or at least issuing a warning that bearings should be treated with a certain amount of suspicion.

It is providential that in many cases the presence of night effect can be detected by experienced operators, and it will be shown later that, by means of the heart-shaped diagram of reception, almost all conditions of night effect may be recognised.

Symptoms of Night Effect. The principal ways in which the presence of night effect makes itself known, when using the figure eight reception, are as follows :—

(*a*) Minima are indefinite but the bearing is correct on taking a swing bearing and matching intensities on either side of the impure minimum.

(*b*) Minima are crisp but displaced.

(*c*) Minima are indefinite and displaced.

(*d*) In the case of reception from a spark station, a change occurs in the character of the note on passing through the minimum point.

(*e*) When position finding by means of cross bearings during night effect periods, a total inability to get satisfactory

intersections is not uncommon, and the " cocked hat " may be ridiculously large.

(*f*) Rapid variations take place in the intensity of signal strength, which falls at times to zero.

Types (*a*), (*c*) and (*d*) are not dangerous in that they are recognisable, but type (*b*) can only be detected (when using ordinary figure eight reception) by taking check bearings on stations, the true bearings of which are known. Even this type of checking will not always show up the effect, since, as we shall see later, the extent of the error is dependent upon the transmitted wavelength and also on the distance between the transmitting and receiving stations, so that one station may exhibit the effect whilst another does not.

A Modern Theory of Night Effect. A very workable hypothesis in connection with night effect arose from directional wireless observations taken of aeroplanes during the European War. It was noticed that serious discrepancies occurred in their apparent bearings even when measured during daylight, and were affected very greatly by the relative direction of flight of the machine. These effects were finally ascribed to the type of wave which is radiated by an aeroplane aerial and which differs from the normal wave propagated over the earth's surface from a symmetrical shore station antenna. The difference lies in the fact that the lines of magnetic flux in the wave are no longer horizontal, but may be inclined (or polarised) vertically to a considerable extent owing to the oblique position of the aeroplane aerial, relative to the earth's, surface, when the machine is flying. A further factor was introduced by the fact that these waves reached the D.F. aerial with a vertical angle of incidence (as distinct from waves travelling over the earth's surface). (19.)

We will now pass on to note the effect on the directional properties of the simple frame of these two factors, namely :—

(*a*) Vertical polarisation of magnetic field, and

(*b*) Vertical angle of incidence of wave at the D.F.

Polarisation of Electro-magnetic Waves. In Chapter 2, when describing the way in which an electro-magnetic wave induced an E.M.F. in a vertical or a frame aerial, it was assumed in every case that the polarisation of the wave was normal ; that is to say, that the direction of the magnetic field in the wave was parallel to the ground and the electric

field vertical. This is represented in Fig. 128(*a*), which shows an end elevation of a frame aerial and an arrow representing the direction of the magnetic flux of a normal wave, which is approaching the frame. (That is to say, the plane of the wave front is in the plane of the paper.) Fig. 128(*b*) is a side view of the same case in which the frame aerial is now seen in

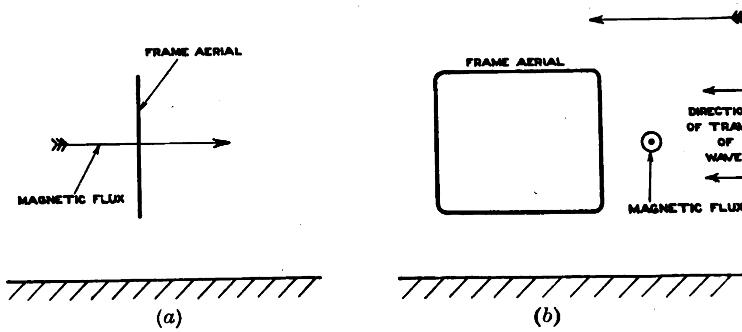


Fig. 128. *Frame Aerial in position of Maximum Magnetic Linkage for Horizontally Incident and Normally Polarised Wave.*

side elevation and the direction of the magnetic field of the wave is shown as a circle with a dot in the centre, which represents the end on view of the arrow head of Fig. 128(*a*). The vertical plane of propagation of the wave is now the plane of the paper.

It was also mentioned in Chapter 2 that no electro-magnetic wave could travel far over the earth's surface unless it were normally polarised, and the reason for this may be explained in a simple manner. Suppose Fig. 129(*a*) to represent again the direction of the magnetic field of a wave, as in Fig. 128(*a*), but with 30 degrees of vertical polarisation. The lines of magnetic flux now make an angle of 30° with the surface of the ground, and cut the earth's surface at their lower ends.

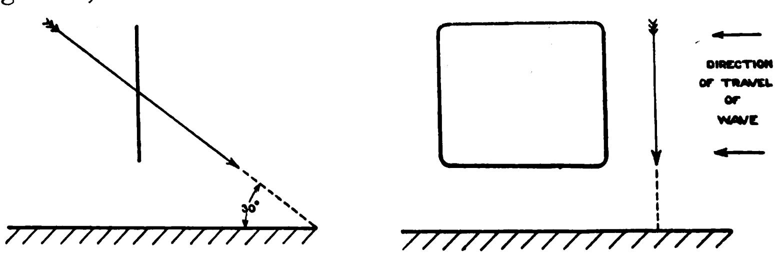


Fig. 129. *Frame Aerial and Horizontally Incident, Obliquely Polarised Wave.*

Fig. 129(*b*) shows again the projection of Fig. 129(*a*) in a direction at right angles.

The magnetic flux may now be resolved into two components, H and V, the first of which is normally polarised and the other, V, is vertically polarised as shown in Fig. 130. The component H will clearly be exactly the same as the flux in Fig. 128, but the V component can never under any conditions

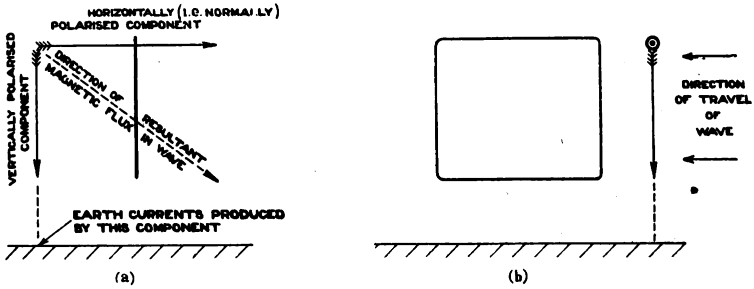


Fig. 130. *Obliquely Polarised Wave, resolved into Vertically and Horizontally Polarised Components.*

induce an E.M.F. in a vertical frame, although it would do so in a horizontal frame, and this method has been used for detecting the presence of the vertically polarised component (65).

Now, we know that when a conductor is moved between the poles of a magnet, or when, say, a piece of copper is held in the field of an alternating current magnet, circulating currents or " eddy " currents are induced in the copper, which dissipate the energy of the magnetic field as heat. In the same way, when an electro-magnetic wave is travelling over the surface of the earth, with a component of its magnetic field cutting the earth's surface, circulating currents are formed which dissipate this component, leaving, after a short distance, only the normally polarised component of the wave. Even during the time that the vertically polarised component persists, it can never link with the frame, since, whatever the orientation of the frame, the vertical lines of magnetic flux will always cut both top and bottom limbs simultaneously, if at all, inducing equal and opposite E.M.F.s round the frame. The vertical limbs can never be cut by a vertical flux.

The Wave having a Vertical Angle of Incidence. In Fig. 131 is shown a wave which is not travelling over the surface of the ground, but is arriving at a receiving frame, with a vertical angle of incidence of 30°. The wave is normally polarised and, clearly, as in the case of a wave travelling

along the ground, the maximum linkage with the lines of magnetic force is obtained when the frame is in the position shown in the figure, namely, having its plane in the vertical plane of propagation of the wave. Since the controlling effect

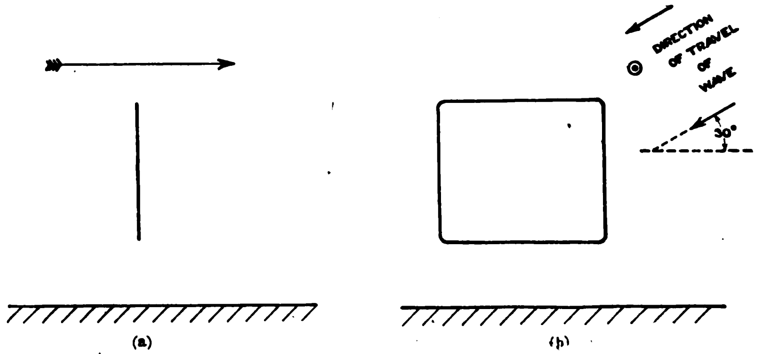


Fig. 131. *Frame Aerial in position of Maximum Magnetic Linkage for Normally Polarised Wave with a Vertical Angle of Incidence.*

of the earth can no longer affect a wave which is travelling in the regions above the earth, and particularly since there are factors tending to rotate the plane of polarisation, such a wave may have a large component which is abnormally polarised. We have therefore redrawn Fig. 131, as in Fig. 132, in which the whole of the magnetic flux is in the vertical plane of propagation of the wave.

[**Note.**—The fact that the wave has a vertical angle of incidence has made it incorrect to refer to the wave as being *polarised vertically*, because the magnetic flux must always be at right angles to the direction of propagation, and so can never be truly vertical. The correct expression would be to say that "the magnetic force is polarised in the vertical plane of propagation of the wave," but the expression "vertically polarised" will be used loosely to mean this except in cases where confusion may arise.]

Referring again to Fig. 132(*b*), one line of magnetic flux is shown passing the frame, but since both are in a vertical plane there will be no cutting of the frame by the flux, and hence no induced E.M.F. When the frame is turned so as to have its plane at right angles to the direction of propagation of the wave, as shown in Fig. 133, there is seen to be a condition of maximum linkage between the upper and lower limbs, and hence a maximum induced E.M.F. The directional pro-

perties of the frame are now invested in the horizontal limbs and the polar diagram of reception is a figure eight, which

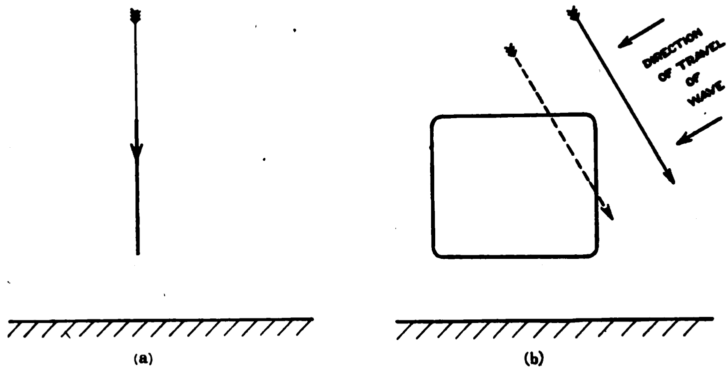


Fig. 132. *Frame Aerial in Position of Minimum Magnetic Linkage for Wave having a Vertical Angle of Incidence and Vertically Polarised Magnetic Force.*

has its *minimum in the direction of the plane of the frame,* as shown in Fig. 134. Compare this with Fig. 14 for the normally polarised wave.

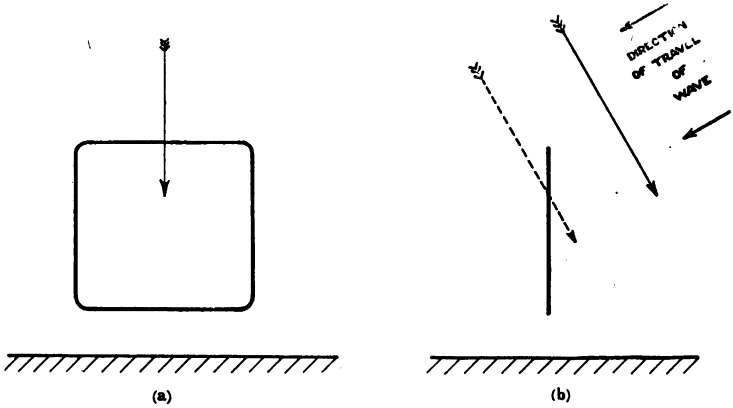


Fig. 133. *Frame Aerial in position of Maximum Magnetic Linkage for Wave as in Fig.* 132.

Clearly, if an attempt were made by means of the simple frame to find the direction of a station which was radiating such a wave as this an error of 90° would result.

Relation between the Direction of Rotation of the Plane of Polarisation and the Direction of Rotation of Apparent Bearing. The two extreme cases of a wave

with a vertical angle of incidence have been considered: namely, horizontally polarised, and vertically polarised; but it is interesting to notice how the position of the frame aerial changes, say for minimum linkage, as the degree of vertical polarisation of the magnetic field is gradually varied. Since this involves movements in three dimensions, the previous set of diagrams cannot easily be adapted to illustrate the conditions at all clearly. The reader will find it far more instructive to take a book in one hand to represent the frame aerial and a pencil in the other to act as a line of magnetic force, and satisfy himself as to the conditions for maximum or minimum linkage with various degrees of polarisation of the magnetic flux.

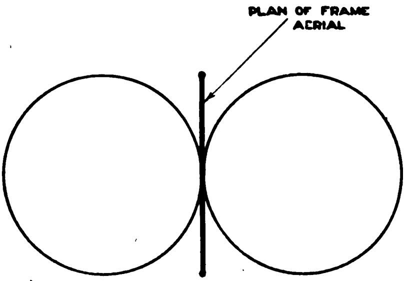


Fig. 134. *Polar Diagram of Reception of simple Frame for Wave with Vertically Polarised Magnetic Force.*

Suppose the pencil in position *a*, Fig. 135, to represent the direction of magnetic force in a wave having a vertical angle of incidence and arriving in the direction of the arrow, the magnetic force being polarised vertically, and therefore in the vertical plane of propagation of the wave. In such a case the position of the frame aerial, represented by the book, for

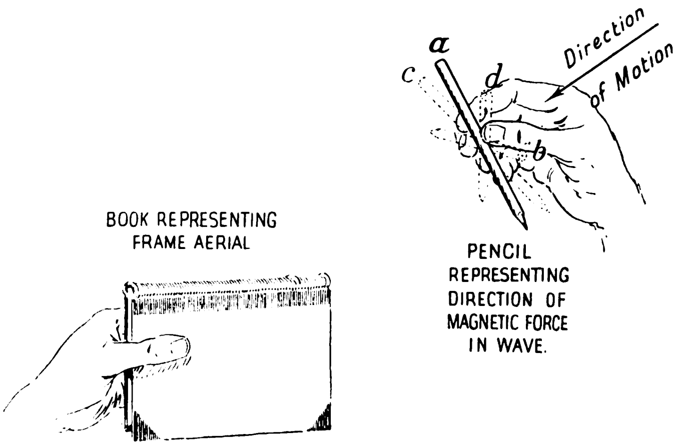


Fig. 135. *Compare Fig.* 132.

zero linkage with the magnetic flux, will be as shown (c.f. also Fig. 132).

Next consider the plane of polarisation to be rotated through a right angle to the direction *b*, Fig. 136, which represents the normal horizontally polarised magnetic force. Then, for zero linkage, the book will also have to be twisted through a right angle.

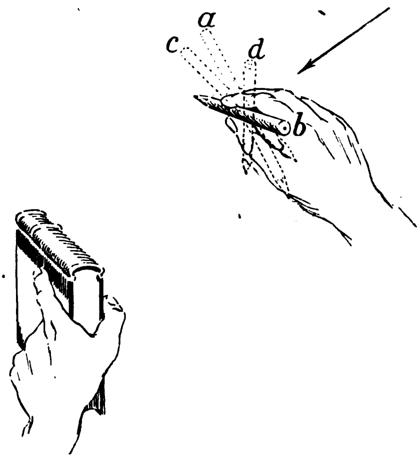


Fig. 136. *Position of Zero Magnetic Linkage for Normally Polarised Wave with a Vertical Angle of Incidence.*

It is more interesting, however, to study the positions of the book for intermediate positions of the pencil. In Fig. 137 the pencil in position *d* is shown rotated through 45° from the starting position and is hence midway between the positions *a* and *b*. In this case it will be found that the book also has to be twisted through 45° in order to keep it parallel to the pencil.

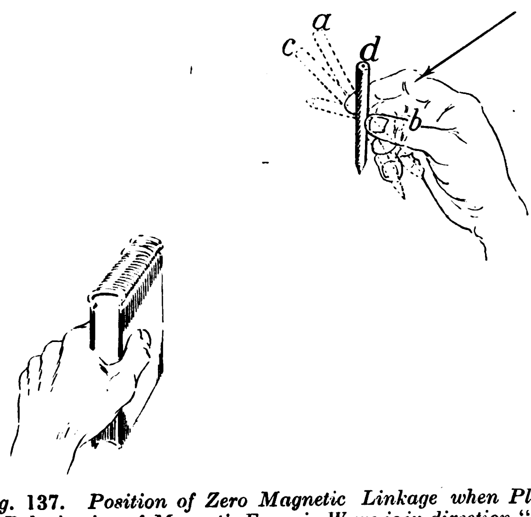


Fig. 137. *Position of Zero Magnetic Linkage when Plane of Polarisation of Magnetic Force in Wave is in direction "d."*

If, however, the pencil be rotated 45° in the reverse direction as shewn in *c*, Fig. 138, then the *book must also be rotated by the same amount in the reverse direction* to maintain zero linkage.

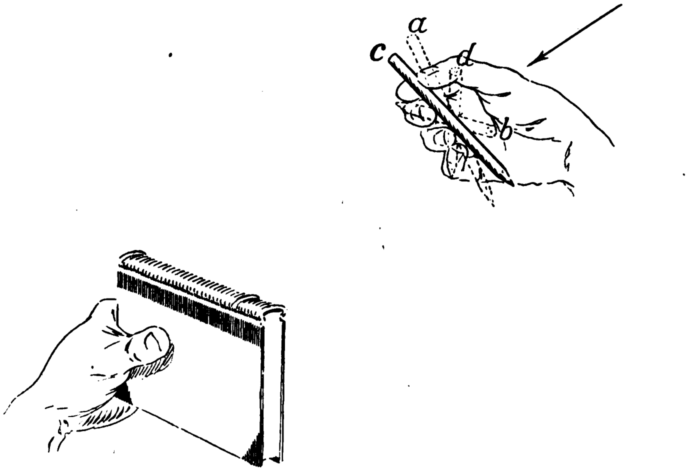


Fig. 138. *Position of Zero Magnetic Linkage when Plane of Polarisation of Magnetic Force in Wave is in direction "c."*

The manipulation of a book and pencil in the above manner, for a short time, will make clear many points concerning the reception, by means of a simple frame aerial, of waves with varying degrees of polarisation, and it will be noticed particularly that the degree and "sense" of the distortion of the apparent direction of an incident wave is governed by the degree and "sense" of the rotation, from normal of the plane of polarisation.

If abnormally polarised wave systems of this nature actually exist, most of the symptoms of night effect can be explained. The indefinite minima, variations in signal strength, distortion of apparent bearing and other effects, may all result from the changing phase relationships of the normal direct wave from the transmitting station, and these abnormal waves which reach the receiving frame by other paths, and arrive with a vertical angle of incidence and a component of vertical magnetic flux.

Before considering the construction of polar diagrams of reception for a simple frame under the combined effect of the normal and abnormal waves from the same transmitter, it will be of value to learn some of the explanations which have been put forward for the existence of these abnormal waves.

Ionisation of Air and the Heaviside Layer. When air is in a normal condition it is an almost perfect insulator, and has little or no appreciable effect upon electro-magnetic waves which are propagated over the earth's surface. Under certain conditions, air, in common with most gases, assumes a conducting state and becomes "ionised," that is to say, the particles of the gas become charged, some positively and some negatively. This effect may be produced by an increase in temperature, by "X" rays, by the rays from radium and similar materials, and from a number of other causes, chief amongst which is the ultra-violet part of the sun's spectrum. During the daytime, therefore, from the last-mentioned cause, the air becomes partially ionised or conducting, hence slightly resisting or opaque to the passage of electro-magnetic waves. As a section of the earth's surface passes into shadow at sunset, re-combination of the ions begins, and the rate of this re-combination is a function of the atmospheric pressure. As a result of this, the lower layers of the atmosphere become de-ionised rapidly, and there exists a fairly well-defined surface between the ionised and normal regions, which surface gradually rises after darkness has set in. Owing to the very low pressures at heights of, say, 50 miles, the rate of re-combination is very slow, and it is probable that a stable condition of the surface is never reached before the sun rises and ionisation begins again. This surface is known as the "Heaviside Layer," and the suggestion that it is sufficiently well defined to reflect the waves which reach it and so provide a second path from transmitter to receiver is illustrated in Fig. 139. Ref. (65),

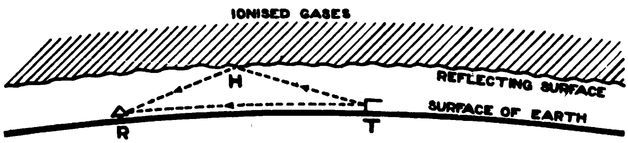


Fig. 139. *Paths of direct and reflected rays from Transmitter to Receiver.*

(72), (80), (81), (102), (109), (126), (129), (131) to (138) (inclusive), (140), (141). It is not necessary that there should be complete reflection of the wave; there may be a combination of reflection and refraction so that the direction of propagation is gradually bent over as the wave penetrates into the ionised regions. This refraction occurs owing to the increased velocity of propagation through air which has a greater degree of ionisation and may even reach the receiving

aerial without any actual reflection having taken place, as shown in Fig. 140.

Under certain conditions it is thought that the waves which reach the receiving aerial from a transmitting station

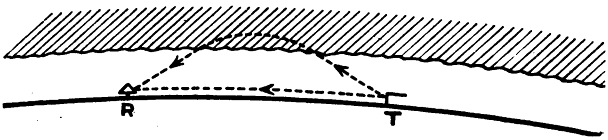


Fig. 140. *Paths of direct and refracted rays from Transmitter to Receiver.*

at a long distance away, may experience a number of complete reflections between the earth and the conducting layer, as shown in Fig. 141. Owing to the fact that the direct wave travels over the surface of the earth, it must arrive at the receiving aerial normally polarised, whilst the indirect wave

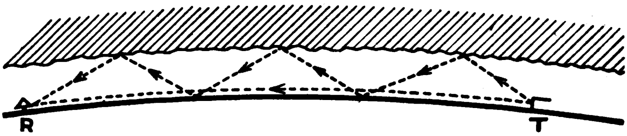


*Fig.*141. *Multiple reflection of indirect ray.*

may have its lines of magnetic force either horizontal, in the vertical plane of propagation of the wave, or at an intermediate angle, and may hence give rise to errors in bearings.

Causes of Vertical Polarisation of Magnetic Field in Reflected Wave. Form of Transmitting Aerial. Certain types of transmitting aerial radiate a wave which has a vertically polarised component in its magnetic field; one such aerial is the common inverted L pattern. The portion of the wave propagated from this aerial, over the earth's surface in a horizontal plane, is normally polarised, but that portion of the wave which does not leave the aerial in this plane, but travels upwards, may have a vertical component of magnetic force and, on being reflected at the conducting layer just described, will reach the receiving frame and give rise to distortion of bearings (19), (65), (66), (127).

Thus, in Fig. 142, A represents the progress of a portion of the wave front of the normal wave between the shore station shown and the ship receiving station. This wave can have no vertical component of magnetic field owing to the proximity of either the surface of the earth or sea (page 167). The portion of this normal radiation which leaves the aerial in a direction

making a vertical angle with the earth's surface, is shown by V_1, and during the dark hours this wave will also reach the receiver by reflection from the Heaviside layer, and may arrive normally polarised, or abnormally, according to circumstances. In addition to these two waves, there is also radiation from the horizontal portion of the L aerial, which will have its magnetic field vertical, as represented by H_1, and this wave, on reflection from the conducting layer, will give rise to dis-

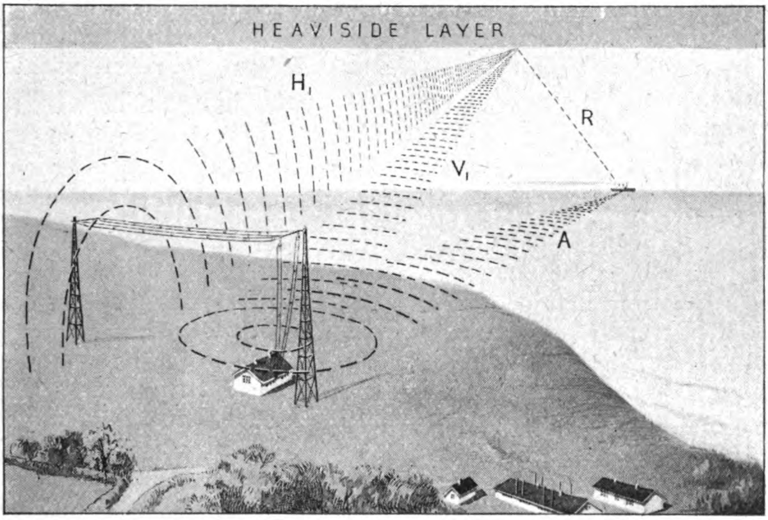


Fig. 142. *Method by which abnormally polarised wave H_1, radiated from horizontal portion of an inverted L aerial, may reach a D.F. Station by reflection.*

tortion of bearings. The effects of this latter radiation can never be noticed during the daylight hours, since it can only reach a receiving station at a distance by reflection, the vertical magnetic field being dissipated at the earth's surface.

It has, in fact, been noticed that when taking bearings at night on two different transmitting stations which are situated close together and working on similar wavelengths, but which have different types of aerial, the apparent bearings during the dark hours may be several degrees different, whilst during the day they are the same (19).

Effect of the Earth's Magnetic Field. It has been suggested that the earth's magnetic field is partly responsible for the rotation of the plane of polarisation of an electromagnetic wave (80). In passing through the ionised atmosphere

it may be assumed to impart a harmonic motion to the ionised particles, and this motion becomes distorted by virtue of the fact that it is taking place in the earth's magnetic field. The new motion of the ions now reacts upon the electro-magnetic wave, and the result can be shown to be equivalent to introducing a vertically polarised component of magnetic flux. On investigation of this theory quantitatively it is found that the assumption of ionised air as a medium for the above-mentioned effects was ruled out by the fact that the effect of the earth's field upon the motion of the ions was negligible. By a process of elimination the conclusion was reached that if the space were filled with electrons, then the earth's field would produce an effect upon their motion which was quite comparable with the effect produced by an electro-magnetic wave (80).

Relative Phases of E.M.F.s induced in a Receiving Frame by the Direct and Reflected Waves. The phase of the induced E.M.F. ~~in a~~ receiving aerial, relative to the phase of the E.M.F. in the transmitting aerial, is a function of the wavelength and the distance between the receiving and transmitting stations. In Fig. 143 the sine curve drawn from the transmitting station T to the receiving frame

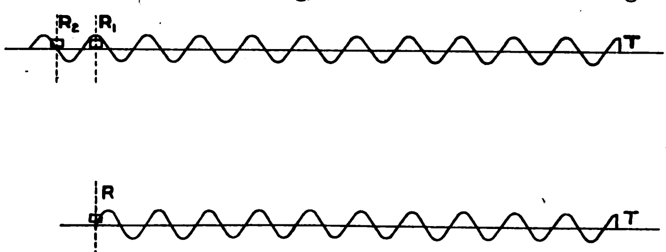


Fig. 143. *Phase relation, at Transmitting and Receiving Station, as a function of distance between stations and wavelength.*

aerial R_1 is to be taken as a measure of the instantaneous intensity of the electro-magnetic force in the path of the wave. It will be noted that the receiving station is ten complete wavelengths from the transmitter. When discussing the method in which a frame aerial receives in Chapter 2, we saw that when the flux in the wave was a maximum, the E.M.F. round the frame was zero, so that in the case illustrated the E.M.F. in R_1 is zero. Had the receiving aerial been, say, at R_2, which is three quarters of a wavelength further away from T, then, at the same instant, the intensity of the flux in the

wave would have been zero and hence the induced E.M.F. a maximum. From this we see that the *distance* is a factor which governs the relative phases of the E.M.F.s in T and R.

In the lower figure we have kept T and R the same distance apart, but the wavelength has been slightly reduced, and we now see that R is at a point of zero flux intensity, indicating that the phase of the E.M.F. in R, relative to that in T, is also a function of the *wavelength.*

Referring again to Fig. 139, it is easy to see that, since the path of the reflected wave THR is greater than that of the direct path TR along the surface of the earth, the two waves may arrive at R with any degree of phase difference, depending on the relative lengths of the two paths and also on the transmitted wavelength. Fig. 139 may now be redrawn as in Fig. 144, in which the intensities of the electro-magnetic forces of the waves are again shown in the conventional manner by means of sine curves. The two waves are here seen to be arriving at R, exactly 180° out of phase, so that, if their mean intensities are equal and if both waves are normally polarised, the E.M.F.s which they induce in the receiving loop will be in opposition and no signals will be received so long as the condition lasts. A change in wavelength, or a change in the length of the transmitted wave, will cause a readjustment of the phase relations at R, and signals will then be heard, the intensity varying from zero, in the case of phase opposition, to a maximum when the two waves are exactly in phase with one another.

It is important to notice that if the reflected wave is normally polarised, no distortion of the observed bearing at R will take place, because the effect upon a vertical frame aerial of a wave with a vertical angle of incidence is the same as that of the direct wave *so long as the lines of magnetic flux are parallel to the earth's surface.*

Phase Relations between the Components of the Reflected Wave. It frequently happens, for one or other of the reasons which have already been suggested, that at night the reflected wave has its plane of polarisation rotated to some extent away from normal, and the consideration of the resultant effect of the direct and reflected wave upon the receiving frame is further complicated by the fact that the latter is not a "plane wave." By this is meant that, resolving the reflected wave into two components, one normally and

the other vertically polarised* (as was done in Fig. 130 in the case of the direct wave), then these two components need not necessarily be in phase with one another. The effect is produced by the imperfect reflection of the two components at the surfaces of the earth and Heaviside Layer, neither of

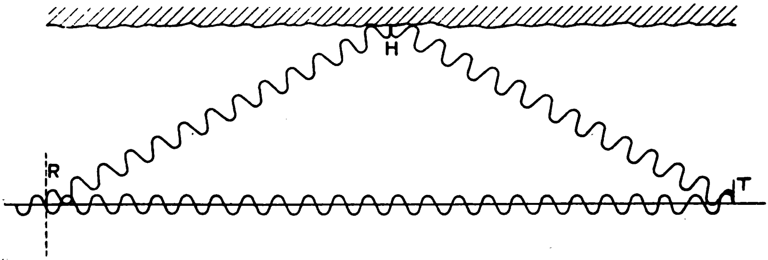


Fig. 144. *Interference effect between direct and reflected waves.*

which are perfect reflectors. It can be shown mathematically that the vertically polarised component always lags about 45° on the normally polarised component. (65).

Summary of Night Effect Conditions. We therefore see that the following three component waves are all influencing the frame aerial during night effect periods :—

A. The direct, normally polarised wave.

B. The normally polarised component of the reflected wave which produces the normal figure eight diagram, but which is not necessarily in phase with A. [Owing to the varying phase relationship between A and B, and also owing to their varying relative amplitudes, the resultant polar curve of reception of the frame may vary greatly in amplitude, although the *direction of the minimum remains correct.*]

C. The vertically polarised component of the reflected wave which produces a figure eight diagram, having its minimum in the plane of the frame (90° in error). This component lags about 45° on B, and depending upon the instantaneous phase and amplitude relations of the other two waves, A and B, this component may cause very considerable distortion of the direction of the minimum of the simple frame.

In subsequent parts of the chapter, when discussing the " mechanism " of the distortion of the minimum by means of

*See the note on page 168 regarding vertical polarisation of reflected wave.

vector and polar diagrams, representing conditions met with in practice, we shall refer to the above three component waves by the letters A, B and C.

Sunset Variations in Signal Strength and Bearing. It has been noticed for many years that the intensity of received signals undergo very violent changes in the neighbourhood of sunset and sunrise, and these variations have been ascribed to some kind of reflection effect at the junctions of the light and dark sections of space which are produced by the earth's shadow. Of later years it has further been noted that the variations in the apparent bearing of the transmitting station which accompany these changes in signal strength are also very remarkable. A careful experimental study has been made by certain observers on these sunset variations, using both figure eight and heart-shape reception, and an analysis of the results obtained seems to form a striking confirmation of the modern theories of night variations. (75).

Experimental Confirmation of Theory of Night Effect. Fig. 145 illustrates a type of extreme variation in bearing

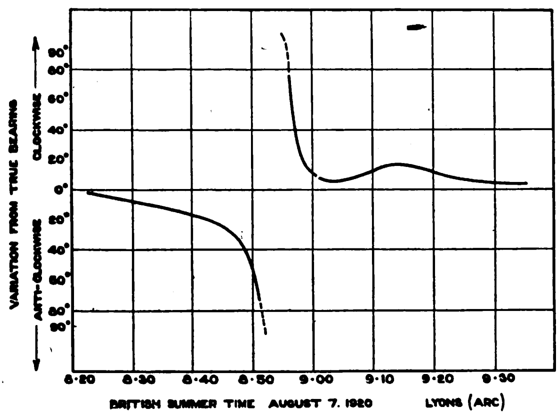


Fig. 145. *Example of extreme variation in apparent bearing.*

which is frequently exhibited by signals from certain transmitting stations, about the time of sunset, at either the transmitting or receiving station. In this case the signals were being received at Chelmsford, Essex, from the French high-power station at Lyons, reception being carried out on a M.-B.-T. circuit with aperiodic aerials and a loose coupled intermediate circuit. It will be noticed that from about 8.20 p.m. the observed bearing began steadily to decrease, and at

M 2

8.50 p.m. was decreasing at a rate of about 8° or 10° per minute. At 8.52 p.m. the bearing was nearly 90° in error, and as the minimum had been getting more and more indefinite it became practically impossible to observe the bearing for a period of three or four minutes.

The minimum then began to become more definite again, and was found to be almost 90° in error in the opposite direction and rapidly returning to normal, so that by 9.5 p.m. the bearing was almost correct again and had settled down to the usual slight night variation.

Owing to the 180° ambiguity of the simple frame diagram of reception, it is, of course, not possible to say whether the true performance is represented by Fig. 145 or Fig. 146, in

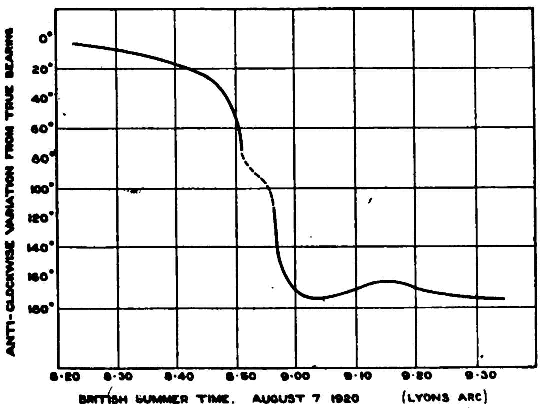


Fig. 146. *Alternative Method of Plotting Graph of Fig.* 145.

which the error is shown steadily to increase to 180°, instead of swinging abruptly from −90° to 90° and returning to zero. Suppose, for example, that Fig. 147 shows the scale of a direction finder with pointer P, and that the correct bearing of a certain station is, say, 100°. Owing to the above phenomenon the bearing is found to be decreasing, and at the same time the minimum becomes indefinite, so that by the time it has rotated to some value 30° it is no longer possible to observe the minimum at all and signal intensity is more or less uniform all round the scale. The observer now makes wide swings with the pointer about the correct value (100°), and after a short interval an indefinite minimum is found at about 170° on the scale, which bearing rotates still in the same direction

and gradually becoming more sharply defined until the correct value of 100° is reached again.

Now, in addition to the minimum corresponding to the correct bearing of 100°, there was the opposite minimum of the figure eight displaced 180° from this one, namely, at 280° on the scale, and this minimum will, of course, also rotate. During the indefinite period of no minima, the apparent bearing may continue to rotate, so that when the minimum is again picked up at the value 170° it is not the same one on which the original 100° bearing was taken, but is actually the opposite (or 280°) minimum which has by this time rotated to 170°. On the above assumption, the graph of Fig. 146 or that of Fig. 145 will be obtained according to whether, after the indefinite period, the bearing is observed by means of the *same minimum* as before or by the *opposite minimum.*

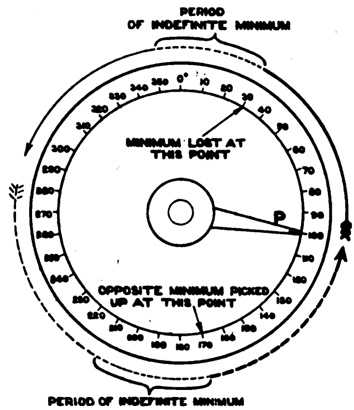


Fig. 147. *Illustrating the* 90° *error phenomenon as plotted in Fig.* 145 *and* 146.

Another possible explanation of the apparent discontinuity of Fig. 145 is that a change of sign of the error occurs when the latter reaches 90° (as shown in Fig. 148), but until we have formed some idea of the "mechanism" of the effect it is difficult to say definitely which of these explanations represents the true state of affairs.

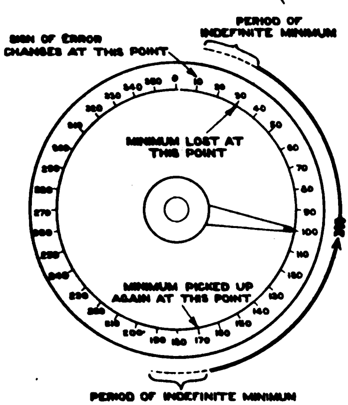


Fig. 148. *Alternative explanation of* 90° *error.*

In Fig. 149 are illustrated two similar occurrences in the case of reception at Chelmsford, from the C.W. transmitting station at Clifden, Ireland. Measurements of signal strength were also taken and a marked reduction in signal strength is noticeable at the centre of each

cycle of variation of bearing. In the second instance, at 9.4 p.m., the signal intensity actually fell to practically zero for a short period.

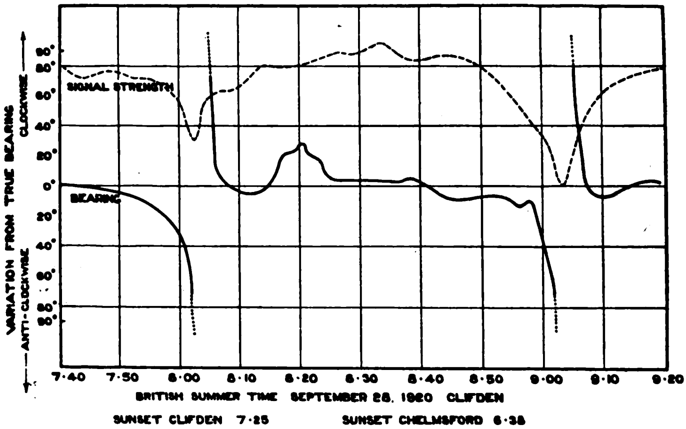


Fig. 149. *Another example of extreme sunset variations in apparent bearing.*

Frequency and Violence of Night Effects. These extreme variations of bearing have been noted on many occasions, occurring sometimes singly, as in Fig, 145, and at other times following one another in rapid succession. Cases are on record in which the apparent bearing of a transmitting station has *made* 3½ *complete revolutions of the scale of the radiogoniometer within an interval of fifteen minutes*, shortly after sunset, corresponding to seven complete cycles of the type illustrated above.

Mechanism of the 90% Error Phenomenon. A simple and very interesting explanation of the above effect can be found in what has already been said regarding simple frame reception under night effect conditions. We will assume that a normally polarised direct wave (A), and also a reflected wave which has a normally polarised component (B), and a vertically polarised component (C), are being received on an ordinary frame. Now it is conceivable that owing to absorption effects, etc., the A wave may be reduced in amplitude until, at the D.F. station, its intensity is equal to that of the B component of the reflected wave. Furthermore, owing to the constant readjustments in height of the reflecting layer, which take place as the sun's light is withdrawn, the length of the path

of the reflected wave is changing and, with it, the phase relations of the A and B waves.

As the condition of phase opposition of A and B approaches, the intensity of signals continues to fall until, at a certain instant, the E.M.F.s due to A and B are exactly opposite in direction round the frame and (supposing them also to be equal in amplitude) the signal strength will be a minimum. During this period of weakening, the E.M.F. due to the C component has been steadily taking more and more effect, until finally only this E.M.F. remains and the figure eight minima are 90° in error. After passing through the phase opposition period, the resultant of the A and B E.M.F.s begins to increase to a maximum again, the effect of the C wave is reduced, and the minima return to their normal positions.

On drawing out the scale polar diagrams representing the events which are taking place, it is found that the minima continue to rotate in the same direction beyond the 90° error as the A and B E.M.F.'s begin to get into phase again, so that by the time the cycle has completed, the bearing may be considered to have swung through 180°. The physical meaning of this 180° rotation is not very clear, and the 180° ambiguity of the frame reception, together with the indistinctness of the minima in the neighbourhood of this point, of 90° error, make it impossible to study closely this part of the cycle.

Owing to the transient nature of the factors which go to produce the above cycle of events, it is not surprising to find that it is not always completed in practice. Very frequently some alteration in the relative amplitudes of the component waves, or in the degree of polarisation of the reflected wave, abruptly interrupts the process and may restore the bearing to its normal value again. For this same reason it is practically impossible to reproduce accurately any extended night effects by means of vector and polar diagrams, but the cycle described above, in which the observed bearing rotates through 180° accompanied at one point by a marked diminution in signal intensity, may be shown fairly simply by the vectorial addition of a number of polar diagrams representing the A, B and C component E.M.F.s.

Graphical Representation of a Type of Night Effect. Let us assume that the B component of the reflected wave is equal in amplitude to the direct wave A. Further, let us suppose that the reflected wave has 30° of vertical polarisation of its magnetic field, so that, resolving it into the two com-

ponents B and C, we see that C=B tan 30°=0.577 B (Fig. 129). In the starting condition we will take B as being in phase with A, and then consider in turn the subsequent cases with B leading 30° on A, then leading 60°, and so on through the complete cycle of 360°. The C component will be taken as lagging 45° on B throughout, in accordance with theory. Before studying the resulting diagrams, which are shown in Fig. 152, it may be helpful to discuss the method of their construction.

Example of the Method of Vectorial Addition of Polar Diagrams. As an example, consider the construction of the diagram of Fig. 152(*f*), in which B is leading 150° on A. In Fig. 150 the large figure eight diagram represents the amplitude of the E.M.F.s induced in the frame aerial XY (supposed fixed) by the A or B waves, for any horizontal angle of incidence. To find the amplitude and phase of the resultant of A and B for any particular horizontal angle of incidence OP we must add the ordinates of A and B in that direction, taking due account of their relative phase, which we have assumed to be 150°.

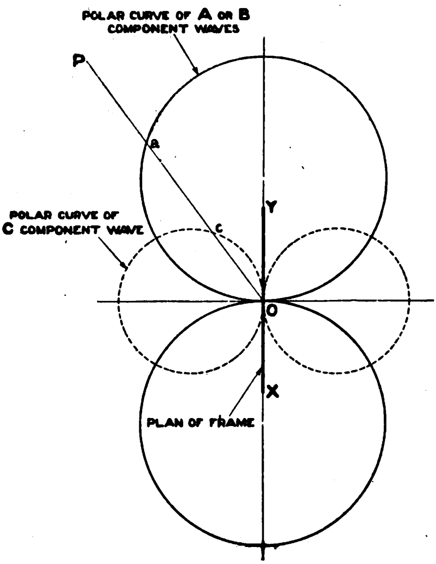


Fig. 150. *Polar Diagrams of A, B and C component waves, using figure eight reception.*

In order to ensure that no confusion shall arise in the summation of the various polar diagrams, it is perhaps advisable to inspect a little more closely the variables with which we are concerned. The intercept Oa is a measure of the maximum E.M.F. which can be induced in the frame due to the wave A when the wave is arriving in the direction PO. This E.M.F. is, of course, a sinusoidal quantity which is varying with radio frequency, so that it is alternately positive and negative in sign but it can never exceed *in amplitude* an amount represented graphically by the length Oa. The

same applies exactly in the case of the B wave (taken as being equal to A in the example), so that Oa is also a measure of the E.M.F. induced by this component and which may be called Ob.

We took a case, however, in which Ob was leading in phase on Oa by 150°, and in Fig. 151 is shown the usual vectorial method of combining the ordinates with due regard to their phase relations. The intercepts Oa and Ob are laid off so that Ob is ahead of Oa in a counter-clockwise angular direction by 150°. Completing the parallelogram, we get OR as a measure of the resultant E.M.F., due to A and B, and which is found to lead on the A E.M.F. by 75°.

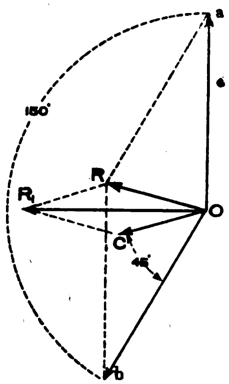


Fig. 151. *Vector Diagram for summation of A, B and C component waves.*

Referring again to Fig. 150, the smaller figure eight diagram represents the E.M.F. induced by the C component wave for various directions of incidence, and it is drawn with its minimum ordinate in the plane of the frame since C is a vertically polarised wave. In the same way as before, Oc is a measure of the maximum amplitude of the E.M.F. due to the C component, for the given direction of incidence of the wave, *i.e.*, PO, and the intercept Oc of the polar diagram must be laid off on the vector diagram Fig. 151 in the direction shown, that is to say, *lagging* 45° on Ob. Oc and OR are now combined to give the final resultant OR_1, which is a measure of the received signal due to all three waves, A, B and C. Continuing this process for, say, every 10° difference in the direction of arrival of the waves in Fig. 150, and drawing a vector diagram in each case, a resultant polar diagram can be plotted out as shown in Fig. 152 (*f*).

We have tabulated below the results obtained from the diagrams of the fourteen different phase conditions of the A and B waves, shown in Fig. 152. The condition of B leading 270° on A is taken first, as this happens to be a condition of zero error :—

Phase Difference between A & B.		Rotation of the Fig. 8 Minima.		Signal Strength Max.	Min.
B leading	270°	0°	180°	1.43	0.58
B ,,	300°	5°	185°	1.75	0.53
B ,,	330°	9°	189°	1.95	0.5
B and A in phase	..	12°	192°	2.0	0.42
B leading	30°	15°	195°	1.98	0.28
B ,,	60°	$18\frac{1}{2}°$	$198\frac{1}{2}°$	1.84	0.15
B ,,	90°	22°	202°	1.51	0.0
B ,,	120°	$29\frac{1}{2}°$	$209\frac{1}{2}°$	1.15	0.28
B ,,	150°	48°	228°	0.75	0.40
B ,,	165°	$68\frac{1}{2}°$	$248\frac{1}{2}°$	0.63	0.25
B ,,	180°	90°	270°	0.58	0.0
B ,,	195°	$107\frac{1}{4}°$	$287\frac{1}{4}°$	0.59	0.21
B ,,	210°	$129\frac{1}{2}°$	$309\frac{1}{2}°$	0.66	0.38
B ,,	240°	166°	346°	1.02	0.55

The scale of signal strength is based on a unity value which is equal to the maximum simple frame signal intensity of the A wave alone.

Comparison of Theoretical and Experimental Graphs. In Fig. 153 the variation in bearing has been plotted against the phase relation of the A and B component waves, and a close resemblance is found between the resulting curve and the experimental curve of Fig. 145. An interesting point is that the apparent bearing is correct when B leads 270° on A, and it is 90° in error when B leads 180° on A; that is to say, three-quarters of complete phase cycle later. The apparent bearing then swings through the next 90° in the remaining quarter of a cycle. In both the experimental graphs Figs. 145 and 149 the same effect is to be noticed to some extent, namely, a slow variation for the first 90° rotation of the bearing and a rapid swing for the remaining 90°. The change in signal strength with variation in bearing also compares fairly well in Figs. 149 and 153.

The fact that the minima are sharp in the case of the theoretical diagrams may be accounted for by the fact that a particular case was assumed, for the sake of simplicity, in which the A and B waves were exactly equal; the result being that at the instant of phase opposition there remained only the small figure eight diagram of the C component field. In practice this would be an exceptional condition, and clearly any residual effect from either the A or B waves would combine with this C diagram and give a diagram in which the minima

were very indefinite. The example must only be considered as illustrating the very simplest case, without taking account of the varying relative amplitudes of the A and B component waves or any possible secondary effects which are taking place. In spite of this, a marked similarity is noticeable in the curves.

Discussion of Fig. 149. Fig. 149 is a typical night effect graph (75), and is by no means a unique case; compare, for

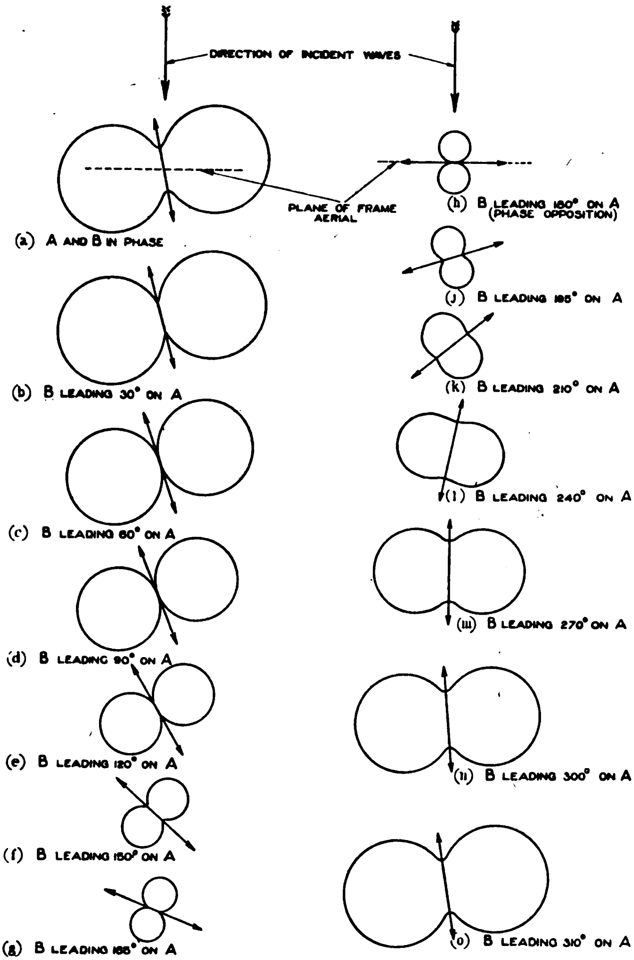


Fig. 152. Series of Theoretical Polar Diagrams illustrating the result of Night Effect on figure eight reception.

instance, the example already mentioned on page 182 in which seven complete cycles occurred. A study of this graph (Fig. 149) reveals a number of very interesting points.

The period of 1 hour 40 minutes over which the observations were made may be divided fairly sharply into four distinct sections as follows :—

(*a*) 7.45 to 8.10 p.m.—Complete cycle of variation of apparent bearing, with reduction of signal strength corresponding to the theoretical reasoning stated above.

(*b*) 8.10 to 8.30 p.m.—Gradual displacement of the apparent bearing to 30° error and return to normal.

(*c*) 8.30 to 8.50 p.m.—Bearing swings slowly from positive error to small negative error.

(*d*) 8.50 to 9.10 p.m.—Complete cycle of variation of bearing *in same direction as before* with reduction of signal strength practically to zero.

Since the observations were started within an hour of sunset, the Heaviside Layer might be assumed to be still rising fairly rapidly. Now, the time taken for each of the complete cycles of variation in bearing (*a*) and (*d*) was roughly 20 minutes, and the two intermediate periods of variation are also of the same length, so that we may assume that each of the four periods corresponds to a complete phase cycle of the A and B waves. (Owing to other causes, only the first and the last period of rotation resulted in the complete 90° swing.) If we may suppose, then, that the time taken for A and B components to go through a complete phase cycle is approximately 20 minutes, then, knowing the distance between Chelmsford and Clifden to be roughly 740 kilometres and the wave-length of Clifden to be 6,000 metres, we can

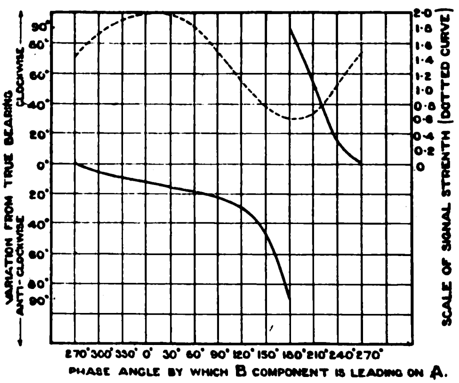


Fig. 153. *Results of Fig.* 152 *plotted to show their resemblance to Fig.* 145 *and* 149.

find, either by calculation or graphically, the relation between the height of the reflecting layer and the speed at which it is rising. The length of the path of the reflected wave will, of course, have to increase by one complete wavelength for each cycle of phase change of A and B.

Throughout the whole series of observations from which the curves in Figs. 145 and 149 have been chosen, it was noticed that the variations started comparatively abruptly a short time after sunset, the exact period which elapsed depending on the relative positions of the transmitting and receiving stations. After a period of an hour or so of violent variations in bearing and signal strength, the conditions usually settled down to the normal night character or erratic variations of smaller degree (75).

The importance of these experimental results lies chiefly in the fact that they form a striking confirmation of the theories as to the part played by the Heaviside Layer in night variations of signal strength and bearings.

DIRECTION FINDING IN THREE DIMENSIONS.

From time to time there have been put forward apparently ingenious methods of finding the complete direction, say, of an aeroplane transmitting station, by means of a system of frames capable of rotation in more than one plane. By "complete" direction is meant the vertical angle of the incoming signals at the receiving station as well as the horizontal angle. The futility of certain such devices can at once be appreciated from what has been said in this chapter concerning reception by frame aerials.

To consider the case, as illustrated diagrammatically in Fig. 154, suppose that A is a frame aerial mounted in a vertical plane and free to rotate about a vertical axis. To this frame is attached a base which supports a second frame B, which is free to rotate about a horizontal axis which is parallel to the plane of the vertical frame, as shown. Now, suppose it is desired to take bearings on a station from which the signals are arriving with a vertical angle of incidence. Suitable receiving circuits being associated with the two frame aerials, the frame A is rotated until the minimum signal strength is obtained, when the centre line of the system X Y is assumed to be in the horizontal direction of the trans-

mitting station. The frame B is then rotated in an attempt to obtain the vertical angle of incidence.

If the wave arriving at the receiver is a normally polarised one, then, since the magnetic field will be parallel to the earth's surface, no signals can ever be obtained on the B frame, since there will be no linkage for any position of the frame. On the other hand, the A frame will give the correct horizontal bearing.

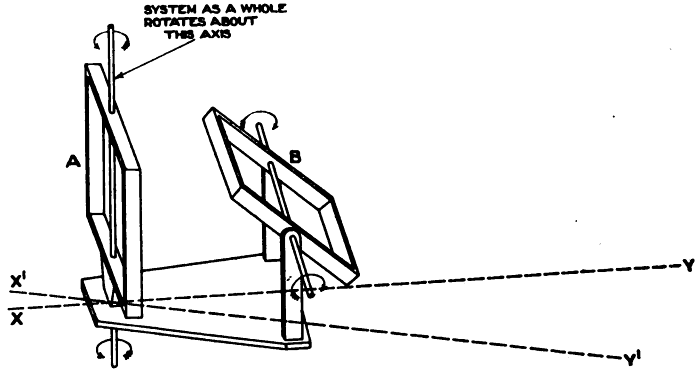


Fig. 154. Suggested device for obtaining azimuth and zenith angles of a source of electro-magnetic waves.

If, however, the wave radiated is not normally polarised, as is frequently the case with aeroplane transmitters (see page 165). then the results will be still less satisfactory. The A frame will now have its position of minimum reception when its plane is in some direction X′ Y′, owing to the equivalent of "night effect" in the received wave, thus distorting the horizontal bearing.

Under these conditions both the normally and abnormally polarised components of the wave will be received by the B frame. The vertically polarised magnetic field will cut the frame in all positions except when at right angles to the vertical direction of incidence, so that, so far as this component is concerned, the correct vertical angle should be indicated. Owing to the fact, however, that the whole system is rotated from the correct horizontal bearing XY to the incorrect one X′Y′, the horizontal frame will now also be cut by the horizontally polarised magnetic field, thereby distorting the otherwise correct zenithal bearing. These facts may be easily checked by a book and pencil in the manner indicated on page 170.

The writer remembers reading more than one patent application claiming three dimensional wireless direction finding on the strength of a device similar in principle to that illustrated above, but the solution of the problem would scarcely appear to come within the province of the simple rotating frame.

OTHER COMMON TYPES OF NIGHT EFFECT.

Land and Sea. It has been noticed that when an expanse of sea separates the transmitting and receiving station, the night variations are usually not so violent as when the waves have to pass over intervening land. Mountainous country gives rise to very bad errors in bearings at night. This would appear to be due to the fact that over sea the attenuation of the direct wave A is small and hence the C component has less effect in distorting the bearing, since the amplitude of the resultant of the A and B waves (page 178) remains fairly large through all conditions of phase relation. On the other hand, over land—and particularly over mountainous country—the attenuation of the direct wave may be considerable, and the conditions described on page 182 may result, in which the C component, during the periods of phase opposition of A and B, is practically the only signal received, with consequent errors.

Marking and Spacing Wave Discrepancies. An occurrence which is by no means rare in the case of reception from a continuous wave station, which uses slightly different wavelengths for marking and spacing signs, is that the apparent bearings of the signals on the two wavelengths may differ from one another by as much as 30 or 40 degrees. At one moment they may both be approximately correct, and on making observations over a period of, say, half an hour, it will be noticed that first one and then the other bearing will swing through a considerable angle, accompanied by changes in the definition of the minimum.

Remembering that the phase relations of the A and B waves at a receiving station depend on the transmitted wavelength, we can see a possible explanation of this effect. A series of variations similar to those shown in Fig. 152 may be taking place in respect of each of the wavelengths from the station, but owing to the fact that the distance between the receiving and transmitting station is not an exact multiple of both wavelengths, the two cycles of phase relations are

not in step with one another, and so one bearing may appear in error whilst the other is correct, and either or both may have indefinite minima. The series of changes may be heard any evening when night effect is prevalent on listening to and noting the bearings of almost any high-power continuous wave station. In England it has been particularly noticeable in connection with the arc transmission from Horsea and also the French station at Lyons.

Minimum Distance between Transmitter and Receiver for Night Effect. Since the height of the reflecting layer may be as much as 100 miles, it might be expected that night effect would not be experienced over short distances, since the reflected wave would have to travel very much greater distances than the direct wave and hence would suffer considerable attenuation, so that its effect would be reduced. Actually this is found to be the case, and at distances less than about 15 miles, variations are rarely if ever noticed to any appreciable extent. Another and a still more probable cause is that, in the case of stations close together, the reflected wave must meet the reflecting surface almost at right angles, and hence the greater part of the energy passes through the surface instead of being reflected and is so lost to the receiving station.

Spark and Continuous Waves. It has always been noticed that indefinite and distorted minima are more pronounced in connection with continuous than with damped waves. The analysis of a damped wave from a spark transmitter shows that the wave form is composed of a number of component waves of varying lengths, and on the assumption that one, at any rate, of the causes of distortion of bearing is due to the varying phase relations of the A and B waves, it will be realised that only in exceptional cases can the condition of phase opposition of the direct and reflected waves exist for more than a small proportion of the total number of component waves. The presence of night effect conditions can usually be recognised in the case of spark signals, since a *sharp displaced* minimum is exceedingly rare.

Change of Note of a Spark Signal. The curious change in the character of the note from a spark station, which takes place as the D.F. aerial is taken through the direction of observed minimum when night effect is present, is a serious difficulty in accurate D.F. work. It may sometimes be almost impossible to find the position of the minimum, since small

swing readings entail the matching of two sounds which are quite different in character (19). The following is a suggestion which has been put forward to explain the effect.

When night effect is present, the telephone signals are the result of the three component E.M.F.s, due to the A, B and C waves, of which A and B have been seen to produce the normal figure eight polar curve, which changes sign as the plane of the frame moves through the direction at right angles to that from which the signals are arriving. The E.M.F. in the frame due to the C component, however, does not change sign at this point, but is, on the other hand, at its maximum amplitude. Exactly at the minimum point, therefore, the signals are due principally to the C wave, and the note is moderately clear. At a considerable angular distance on either side of the minimum the effect of the A and B waves together is much greater than that of the C wave, and they give a clear note. At the positions, however, on either side of the minimum where the A, B and C components all have effects on the signals comparable with one another, the note may be reduced to merely a hiss, and the reversal of the sign of the A and B waves will result in the combined wave form due to the three components being sufficiently different on either side of the minimum to change the character of the note.

THE ELIMINATION OF NIGHT EFFECT ERRORS IN BEARINGS.

Various methods have been suggested or patented for obtaining the correct wireless bearing of a transmitting station through periods of night effect, which are caused by the presence of vertically polarised magnetic fields in the reflected wave. The more important of these methods are as follows :—

Horizontal Frame. As already mentioned on page 167, a wave having vertical magnetic force will induce an E.M.F. in a frame which is in a horizontal plane. By a suitable circuit arrangement it is possible to balance the horizontal frame E.M.F. against the E.M.F. which is caused by the cutting of the horizontal limbs of the vertical frame by the vertical magnetic field. By this means the C component E.M.F. is eliminated and the bearings are always correct, although variations in signal strength still occur. The system has not had any extensive application in practice (65).

Spaced Vertical Aerials or "Open Frame." In the earlier types of direction finders, such as those of J. Stone-Stone and the original Bellini-Tosi arrangement, the tops of the vertical aerials were not connected by a horizontal member, but consisted simply of open aerials spaced apart a certain fraction of a wavelength. The E.M.F.s in the aerials at any instant were proportional to the flux cutting them, and consequently, by taking the algebraic sum of these E.M.F.s in a suitable circuit, a measure could be obtained of the degree of phase difference, and hence of the orientation of the aerials relative to the direction of propagation of the wave. The system was, in fact, exactly the same as that described in Chapter 2 in the case of the frame aerial, but the E.M.F.s were summed up in a separate circuit instead of in the aerial itself. The addition of the horizontal limbs and conversion of the aerial system to a rotating frame simplified the circuit, but introduced the night effect trouble due to the reception of the vertically polarised magnetic field. Adcock, in his patent, has returned to the older method for the express purpose of avoiding this trouble, and by also suitably disposing the lower horizontal limbs which connect the vertical aerials to the receiving circuits, he ensures that no vertical field can have any influence on the system. The arrangement is illustrated in Fig. 155.

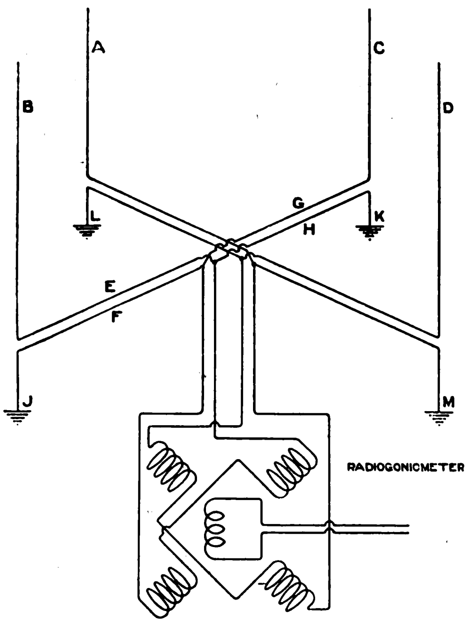


Fig. 155. *Adcock's Scheme for elimination of Night Effect.*

Spaced and Opposed Frames (Franklin and Weagant Aerial). If two frame aerials are connected in opposition, as shown in Fig. 156, and spaced apart an appreciable fraction of a wavelength, the system is found to have directional properties which are unaffected by night

effect conditions. Consider, firstly, the normally polarised wave arriving in the direction P, that is in the plane of the frames. This wave will induce an E.M.F. in each frame, and since they are connected in opposition, the resulting E.M.F. in the receiving circuits will be that due to the varying intensity of the electro-magnetic force in the wave at points spaced some distance apart in the path of the wave.

Now consider a wave arriving in the direction Q, that is, at right angles to the plane of the frames. No E.M.F. will be induced by such a wave in either frame, since all the four vertical limbs will be cut simultaneously by the wave front.

If, now, a wave arrive in the same vertical plane as the direction of Q, but having a vertical angle of incidence and vertical magnetic field, then the magnetic flux will cut the frames, as shown by the dotted arrows. Equal E.M.F.s will be induced in each frame, and since the frames are in opposition there will be no resultant E.M.F. in the receiving circuits. Again, suppose a similar type of wave be arriving in the vertical plane of the frames, then since both the frames and the magnetic field are vertical, there will be no linkage with the frames whatever (44).

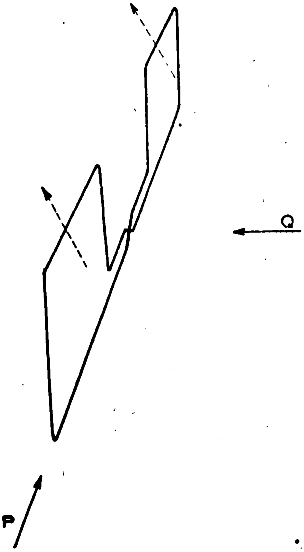


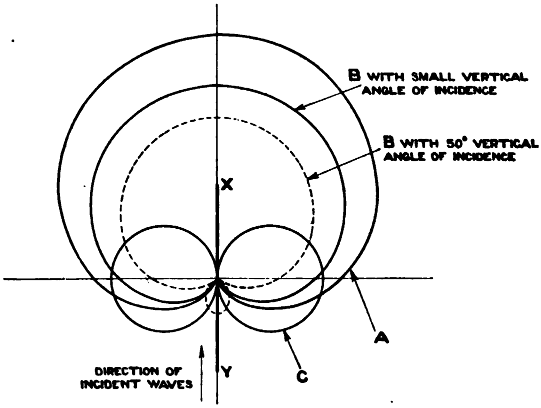
Fig. 156. *Franklin and Weagant spaced and opposed frames for elimination of Night Effect.*

Clearly this aerial system is immune from effect by vertically polarised magnetic fields, but the cost of such an aerial system and the space which the station would cover renders it impracticable for ordinary D.F. working, although it has extensive use in special cases. A further difficulty is that of making any such system to work on a number of wavelengths. If the frames are spaced at the best distance for a 600-metre wave, the reception on 6,000 metres would be very indifferent and *vice versa*.

The Heart-shaped Diagram. In Chapter 2 it was seen to be possible, by combining the E.M.F.s induced in a frame and a vertical aerial under certain conditions, to obtain a

polar diagram which has only one minimum, and that this minimum lies in the plane of the frame aerial. Since this is the direction in which the wave with a vertical magnetic field also has minimum influence upon a simple frame, a possible method of eliminating night effect is presented.

In Fig. 157 suppose XY to represent a plan view of a frame aerial and the arrow to show the direction of arrival of the



157. *Polar Diagrams of A, B and C component waves using heart-shape reception and when the reflected wave has a vertical angle of incidence.*

three component waves A, B and C from a transmitting station, the aerial having been adapted by means described in Chapter 2 to give a heart-shaped diagram on a normal wave.

The C component cannot be received by the vertical aerial, owing to the fact that its magnetic field is in a vertical plane and hence the diagram obtained in respect of this wave will be the figure eight diagram C and not a heart-shape. The A wave will produce a normal heart-shape and the B-component will also give a heart-shape, as shown in the figure, with the same circuit adjustments as A, provided that the vertical angle of incidence of the reflected wave is not too great. If this angle is as much as 50°, say, then from Fig. 158 it is clear that the number of magnetic lines of force in the wave which cut the vertical wire will not be proportional to the length *ab*, as in the case of the A wave, but will be proportional to *ab'*, which is the projection of *ab* at right angles to the direction of incidence of the B wave. The vertical wire E.M.F. will now not be great enough to give a true balance on B, although it will be correct for A, and the resulting diagram for B will be as

shown dotted in Fig. 157, resulting in an impure minimum. There is good reason to believe, both from theoretical and experimental evidence, that the vertical angle of incidence is rarely sufficiently great to cause any appreciable difficulty in obtaining a heart-shape balance on both the A and B waves.

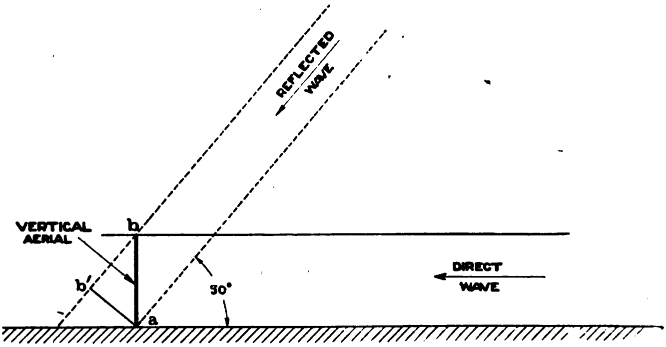


Fig. 158. *Reduction in receiving power of vertical aerial when reflected wave has a large vertical angle of incidence.*

If there had been more than one reflection of the B wave, as shown in Fig. 141, then the angle of incidence would be greater; but we have already seen (page 192) that a large vertical angle of incidence results in a very weak intensity of reflected wave.

From Fig. 157, then, it appears that no matter what the phase and amplitude relations of the three component waves, no signals can ever be received in the direction of the normal heart-shape minimum.

Graphical Representation of the Heart-shaped Polar Diagram under the Influence of Night Effect. For the purpose of comparison with the series of polar diagrams for the simple frame under night effect conditions, shown in Fig. 152, a similar series have been drawn out to scale for heart-shape reception. The conditions taken are the same as before, namely, the A and B components equal, and the C component equal to 0·577 times A or B and lagging 45° on B. The series is illustrated in Fig. 159.

The first point to be noticed in the case of these polar diagrams is the impossibility of taking swing bearings about the minimum, owing to the unsymmetrical form of practically all the curves. It will also be seen that although a well-defined zero of signal strength always exists in the plane of the frame, a second minimum may also occur, and in the case when B

is leading 90° on A, this second minimum is also a zero value displaced about 44° from the correct value. This effect of two true zeros of signals occurs whenever the C component

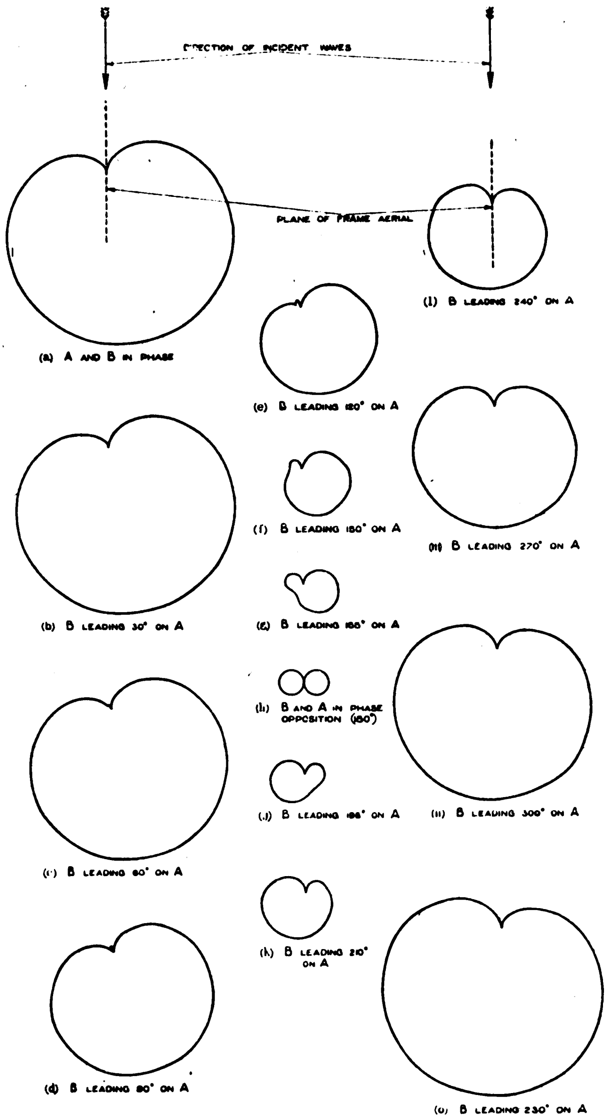


Fig. 159. *Series of Polar Diagrams as in Fig.* 152, *but using Heart-shape Reception.*

is in phase with the resultant of the A and B components. Under the same conditions, in the case of the figure eight polar diagrams Fig. 152, it will be noticed that true minima are obtained, that is, complete zeros of signal strength, but the direction of the minima is displaced some 22° from the correct value of bearing.

In Fig. 160 are shown portions of these two diagrams 152(d) and 159(d) to an enlarged scale and superimposed one on the other. The heart-shape curve is shown in full lines and the figure eight dotted, and a curious fact is at once noticeable regarding the directions of the minima of the two diagrams, namely, that the error in bearing of the second heart-shape minimum is exactly double the error of the bearing given by the minimum of the simple frame. An illustration of a practical case of this effect to quite a marked degree is shown in Fig. 161 and will be referred to again.

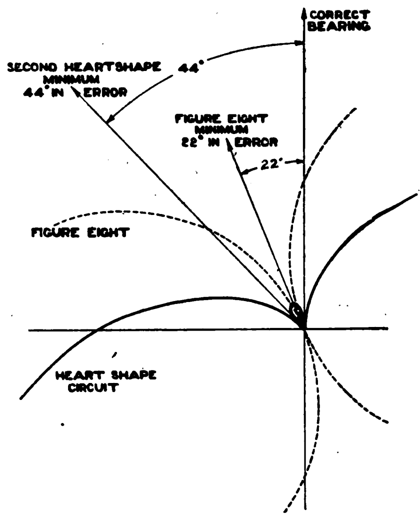


Fig. 160. *Enlarged View of part of Fig.* 159(d).

Owing to the fact that the A and B waves have been considered to be equal in amplitude, we see in Fig. 159(h) that when these two components are in exact phase opposition only the figure eight diagram of the C component remains. In practice (as was pointed out on page 186 in connection with the similar set of diagrams for the simple frame) there is usually a slight residual effect, due to either the A or B component, which is large enough to prevent this true cosine diagram ever being obtained on the heart-shape circuit. The remainder of the diagrams, however, are all representative of night effect conditions of practical heart-shape reception.

Comparison of the Simple Frame and Heart-shape Circuit in Practice. It is very instructive to make a comparison of the simple frame and heart-shape circuit during a period of pronounced night effect. In order to do this the

heart-shape circuit should be adjusted during the daytime on a station the bearing of which it is desired to observe, and preferably one which is known to exhibit night variations to a considerable extent. Provision must be made for switching out of circuit the vertical aerial so that the figure eight remains alone.

The example which was chosen to illustrate the graphical way of reproducing types of night effect polar diagrams (Fig. 152 and 159) was, of course, only one of an infinite number of possible conditions, and in practice a very large variety of effects may be observed which do not seem to coincide with any of the diagrams shown in these two figures. In Fig. 161 and 162 are shown some of a large number of freehand sketches made during the set of observations mentioned above (75). In each case the dotted curve is the diagram of the simple frame and the full line is a portion of the heart-shape polar curve. The sketches can, of course, only roughly represent the actual conditions, but care was taken in their reproduction and they may be taken as a fair estimate of the truth.

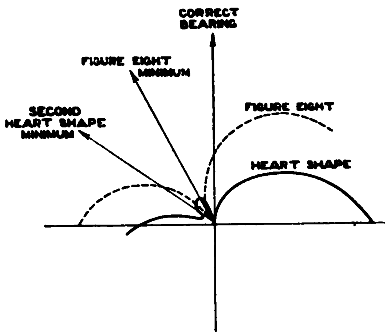


Fig. 161. *Figure eight and Heart-shaped Polar Diagrams under influence of Night Effect. Freehand sketches during actual aural reception.*

Fig. 161 has already been mentioned, and this is a type of diagram which is not at all uncommon. On many occasions observers have noticed the double minimum of the heart-shaped diagram, and in almost every case, on rapidly switching on to the simple frame diagram, a well-defined minimum was obtained about half-way between the positions of the two minima of the previous circuit.

The four sets of diagrams in Fig. 162 show fairly plainly another characteristic of the heart-shaped diagram under the influence of night effect. It will be noticed that in Fig. 162(*b*), (*c*) and (*d*) the heart-shaped diagram is very flat in the direction of rotation of the minimum of the figure eight diagram, although the portion of the curve on the other side of the minimum (marked x) is almost identical in all three

cases. This same fact is also to be noticed in the diagrams of Fig. 159.

Fig. 162 (c) shows clearly the great advantage of the heart-shape circuit, the minimum of the simple frame being a perfectly-well defined point of zero signal strength which is 90° in error and Fig. 162(d) is a very similar case.

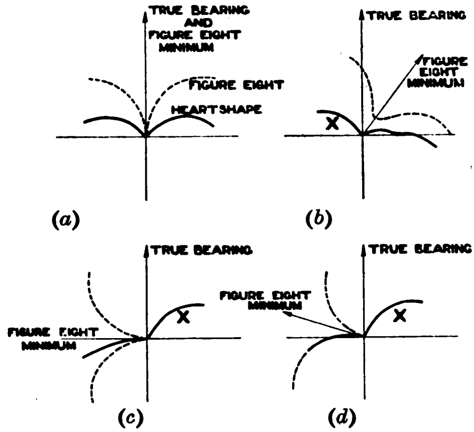


Fig. 162. *Further sketches made during aural reception illustrating assymmetry of Heart-shaped Diagram whilst direction of zero reception remains correct.*

The inability to take swing bearings is undoubtedly a great disadvantage of the simple heart-shaped diagram, and although methods exist, in an experimental form, for producing polar diagrams which are symmetrical about a single minimum under all ordinary conditions of night variation, no simple practical form has yet been devised which will be suitable for commercial D.F. work.

Value of Heart-shape Circuit in Detecting Presence of Night Effect. The chief function of the heart-shaped diagram in D.F. work remains that of determining " sense," but it is also extremely useful in detecting the presence of night variations. The lack of symmetry is a valuable warning of the approach of night effect periods, and has always been observed to be quite pronounced on the heart-shape circuit, before the night variations have manifested themselves on the simple frame circuit, either by distortion or indistinctness of the minimum. A heart-shape thus affords a method of checking the figure eight results from time to time to ensure that reliance is not being placed on clearly defined but incorrect minima.

CHAPTER 7.

THE SHORE D.F. INSTALLATION.

Many of the factors of which account must be taken when erecting a shore D.F. station are common to all wireless receiving stations, but a number of additional precautions have to be taken which are peculiar to this branch of reception. Having decided upon the locality of the station from the point of view of its zone of action, the neighbourhood must be carefully inspected for a suitable site and, if possible, for one or two alternative sites in case the first should develop unexpected disadvantages when tried out. The direction of the meridian through the ultimate site must be known for the purpose of calibration, and the exact geographical position of the station is required to at least the same degree of accuracy with which it is hoped to operate the system.

The aerial system needs more than ordinary care in construction, and special points arise in the installation of the receiving apparatus. Finally, the station must be calibrated to ensure that bearings are correctly rendered from all directions, avoiding wherever possible the necessity of anything in the nature of an "error chart."

Choice of Site. Considerable care is necessary in choosing the site for a D.F. station. A position in an open field, in flat country, and with the nearest trees or buildings more than a wavelength distant, is seldom realised in practice, although this may be considered ideal. When masses of conducting or semi-conducting material exist within a small fraction of a wavelength from the station, there is every probability of errors being introduced in the bearings in the neighbourhood of the directions of these objects. After the station has been erected, there are methods which will be explained under the heading "Calibration," page 254, whereby the errors can often be reduced to a negligible amount; but these corrections should not be reckoned upon as infallible, and every effort should be made to secure a clear site.

The errors which are introduced may be of various types. If the station be erected within a short distance of a long conductor, such as a telegraph line or railway metals, there may be a deflection of a portion of the wave front in the neighbour-

hood of the D.F. station, or reception and re-radiation of energy from the conductor, which will give the station a greater apparent receptive power in one direction than any other, with consequent errors. (See " Quadrantal Error," on page 258.) Large and more or less compact conductors, situated at less than about a quarter wavelength (the distance depending on their size and nature) will produce screening from stations in their direction with consequent deviations in observed bearings (118), (139).

Sudden changes in the nature of the surface of the ground, such as a line of rocks, produce errors due to reflection if they are behind the station, and a site chosen at the edge o: cliffs or inland rocks can scarcely hope for reliable results until careful calibration has been carried out. It is found, as a rule, that a station erected on high ground near the edge of cliffs is less accurate for long waves than short ones, when the cliffs intervene between the D.F. station and the distant transmitting station. For this reason it is advisable to put the station not less than a wavelength distant from the cliff edge, if possible. Secondary effects occasionally prevail, however, and at least one English coast station was found, during calibration, to be more accurate on long than on short wavelengths.

Apart from reflection errors, there is also refraction or bending of the path of the waves whenever their path crosses at an acute angle, a discontinuity or change in the nature of the conducting surface over which they are travelling. This type of error has already been mentioned on page 161, and the effects may, in practice, be of a very confusing nature, particularly when the path of the waves crosses a coast-line. For this reason careful attention must always be given when calibrating a coast station, which is to be used for directing ships at sea.

The surface of the ground should always be as nearly level as possible, otherwise the base members of the M-B-T aerials may not all be the same distance from the ground, resulting in out-of-balance capacity effects which will introduce a form of " vertical component." This is of more frequent occurrence in ship installations, and is discussed on page 268.

It should go without saying that the proximity of a wireless transmitting station may cause endless trouble by jamming or may cause distortion if very close to the D.F. and tuned to the D.F. wavelength, or near it.

Power mains are another frequent source of interference, and D.C. mains are quite as bad as A.C. The direction finder is usually equipped with an amplifier having up to six valves in cascade, and possible note or audio frequency magnification as well, so that the ripples of current due to bad commutation in an adjacent D.C. main may easily produce considerable noise in the telephone receivers. This type of disturbance is almost fatal to accurate direction finding, as the noise will usually have a definite direction and will not be of equal intensity all round the scale.

Providing the offending machine is accessible to the person erecting the D.F. station, it is possible to reduce the noise due to bad commutation of either a motor or generator almost to zero by means of condensers and chokes suitably connected across the brushes and to earth. Where possible, power mains should always be armoured and buried, if it is necessary that they should be brought near the station.

Summarising, then, the following points should be taken into account when circumstances permit, and if reasonable care be taken in the selection of the site, no serious trouble need be anticipated :—

Railway metals.
Telephone and telegraph lines.
Isolated trees or small groups of tall trees near the station.
Tall buildings.
Cliffs.
Coast-line.
Sloping ground under M-B-T aerial system.
Iron fencing or wire netting.
Power mains in open, or power wiring of building.
Adjacent transmitting or receiving aerial.
Electrical machinery of any kind (running).

Fixing the Geographical Position of the Site. In the British Isles the most simple method of finding the latitude and longitude of any place is by reference to the Ordnance Survey maps, but no other map should be used unless published by a reliable authority. Unless the site has been chosen in a particularly barren locality there will rarely be any great difficulty in finding the exact position of the station on the survey map, but in cases where doubt exists the geographical method of finding the direction of the meridian through the site, which is explained on page 207, may be adapted to find

the position of the station by the "triangulation" methods of ordinary surveying. This process corresponds exactly to that of a "Fix by Cross Bearings on Short Range Stations," given on page 157, except that, of course, there is no movement of the ship to be taken into account, and there must be no "cocked hat" when these optical bearings are plotted on the map. If the lines do not intersect exactly at one point, the bearings should be checked and re-checked until consistent results are obtained.

When the importance of the station seems to warrant the action, the position of the site should always be checked by some other method than the Ordnance Survey alone, though such extreme care will generally only be necessary for experimental stations or stations used by the Army or Navy for strategic purposes.

In countries where reliable maps on a suitable scale are not available, astronomical methods of finding the latitude and longitude are practically the only alternative, and on page 329 *et seq.* a description is given of how this may be done in the simplest manner.

It must be remembered that nautical charts are procurable for all parts of the world, and in some cases a process of triangulation, using beacons, lights, etc., marked on the charts may give consistent results which enable the position of the station to be found when it is near the coast. In general, the astronomical method is to be preferred, and the direction of North may be found from the sun's azimuth at the same time.

Correct Orientation of Station or Aerial System. In order that the bearings as determined by the D.F. may be *true* bearings, it is necessary to determine the plane of the meridian through the site, and then so to adjust the pointer of the apparatus that it reads 0° on the scale for signals incident from the direction of true North. In the case of small rotating frames it is not a very simple matter to make these adjustments, as the electrical axis of the frame does not always coincide with the geometrical axis, unless the frame aerial consists of one turn only, and it is more usual to rely upon a calibration obtained by bearings taken upon transmitting stations the positions of which are accurately known, or else a portable transmitting set is used. In the latter case it becomes necessary to know the true bearing of the portable station, and this,

particularly in the case of coastal stations, may conveniently be done by means of a theodolite or sextant by methods which will be described later. (Page 254.)

In the M-B-T system, since the frame aerials are large and each consist of a single wire, it is usual to erect the two frames in North-South and East-West directions respectively, after which it is a very simple process to make the necessary adjustments in the radiogoniometer in order to obtain true bearings. (Page 256.)

Given a large enough number of distant stations on which to take bearings, or a portable transmitting station the position of which can be found accurately for any required scale reading, there is no necessity to lay out the M-B-T aerials in any special directions; but if unsuspected freak conditions are found to exist when tests are made, it is a great advantage to have a reliable standard for calibration.

To take an example of this, suppose that a station had been erected without any regard to the direction of North. Bearings have been taken on a number of stations, and we will assume that the observed bearing of a station " A " was 31° and that of a station " B " was 115°. On consulting a map or making the necessary calculations, the true bearings of " A " and " B " from the station were found to be 65° and 149°. That is to say, the 0° reading on the scale of the instrument did not represent North, but 34° East of North, since each of the bearings taken was 34° too small. This may be remedied very simply by adjusting the pointer of the radiogoniometer on the spindle until the stations read correctly on the scale in exactly the same way that the hands of a clock are moved when it is found to be " fast " or " slow."

Suppose, however, that in the case just considered station " B " had read 117° instead of 115°. Now, the error between the true and observed bearings is 32°, which is not the same as the error in the case of station " A." The pointer can no longer be adjusted with any degree of confidence, since it is not known which of the bearings is correct, Had the aerials been laid out accurately North-South and East-West, then this would have formed a basis for calibration and steps could at once be taken to investigate the bearing which showed a discrepancy.

METHODS OF FINDING THE DIRECTION OF TRUE NORTH.

There are a number of methods in common use for finding the direction of the meridian through the site selected for a D.F. station, a few of which have been described below and in Chapter 11. These include :—

(A) Geographical method.

(B) Prismatic compass method.

(C) Sun's azimuth.

(D) Sun's meridian passage.

Methods C and D involve a knowledge of the elements of nautical astronomy and have been included in Chapter 11, in which will be found brief reference to a further method of finding the direction of true North by observations on the pole star.

Methods A and B are described below in their application to the case of a M-B-T aerial system, and it should be remembered that reference to "Aerial Stay Anchors," etc., do not apply to the case of the rotating frame installation.

True North by Geographical Method. In the geographical method a reliable map of the district is procured which has the meridians of longitude shown, and on this map is located the exact position of the D.F. station. Bearings are now measured on the map between the meridian through the position of the site, and the directions of various conspicuous distant objects, such as churches, towers, etc., and these are reproduced on the site by means of a theodolite or sextant and the direction of the meridian thereby found.

It should be borne in mind that the available maps of parts of the world in which it may be necessary to erect D.F. stations are by no means as accurate as the ones we are accustomed to use in the British Isles, and a lack of conspicuous objects or low visibility also conduce to bad results. The method has the advantages that it is not necessary to have a clear view of the sun, there are no calculations to be made, and a theodolite is not essential. Whilst it is more convenient to use a theodolite, a nautical or box sextant is quite satisfactory.

Suppose Fig. 163 shows a view of the site chosen for the station. It is found that there are three conspicuous objects which can be seen from the position chosen for the mast, all of which are likely to be shown on an Ordnance Survey.

Fig. 164 is a rough representation of a survey map of the district shown in Fig. 163. [The latitude and longitude have

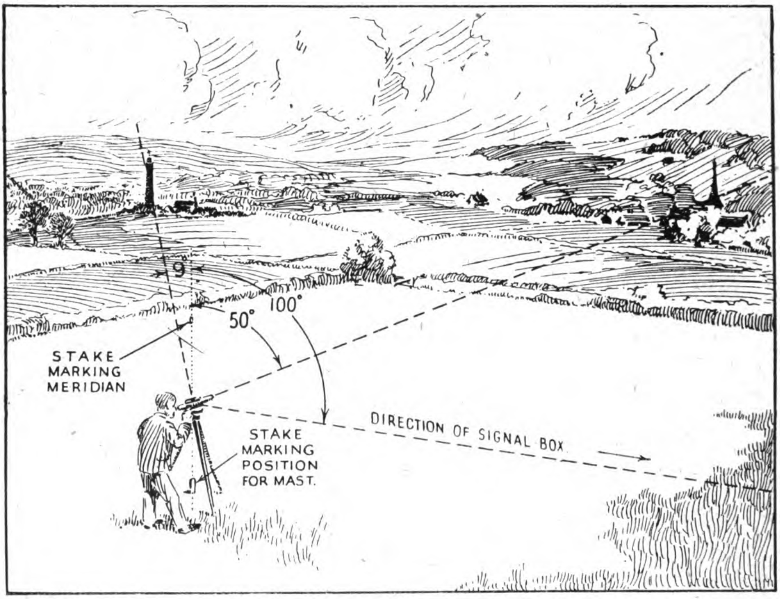


Fig. 163. *Determination of the Direction of North from Bearings obtained from a Map.*

been chosen at random and the map does not represent any real place.]

On the map are marked the objects mentioned above, these being a tower, a church and a signal-box. It may often be necessary to obtain several surveys in order to include all the objects selected for bearings, and in this case care must be taken in joining up the adjacent maps. It is better to pin them out on a drawing-board, rather than attempt to paste them together, as this latter scheme is not at all satisfactory unless well done.

Having found on the map the position of the proposed mast, lines are drawn through each of the objects and the point marked on the map to represent the mast. It is now necessary to fix the meridian through the station, and for this purpose only those maps can be used which have either the meridians drawn or a marginal scale of longitude. In the latter case, by placing a straight-edge across the map, passing through the

site, it may be so adjusted that similar readings on the longitude scale are obtained at either end. Thus, in the case illustrated, a straight-edge placed at the position 3° 2′ 35″ passes through the site. As already pointed out on page 120,

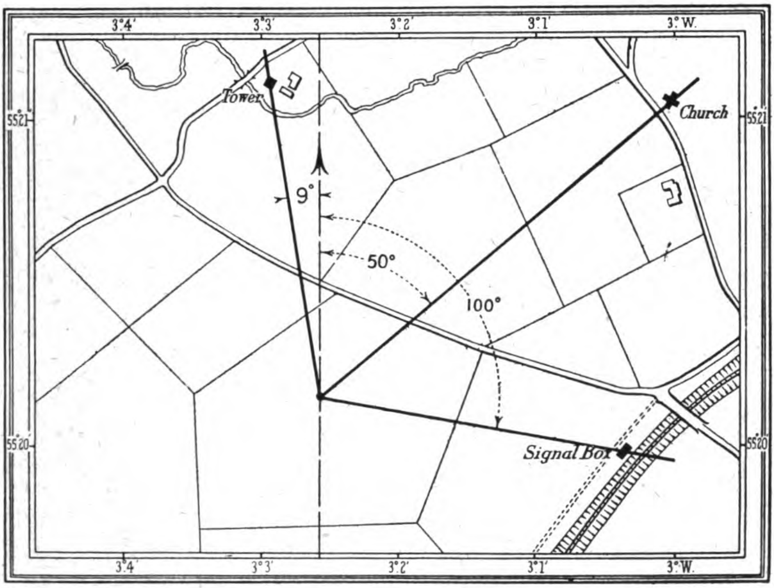


Fig. 164. *Map of District (imaginary) shown in Fig.* 163.

the meridians are very rarely found to be parallel to the sides of the Ordnance Survey map, and if some other sort of map be used in which the meridians are not definitely shown, *it should never be assumed that the boundaries of the maps are meridians or parallels.*

A line having been drawn to indicate the direction of North, the bearings of the objects chosen are measured off from the map and noted. Having driven a stake into the ground to mark the proposed position of the mast, the theodolite is set up so that its plumb-bob hangs over the centre of this stake. If a sextant is being used, provision must be made to ensure that whilst readings are being taken, the instrument is vertically over the stake.

A second stake, which should be made of white wood with a black line marked vertically on one face, is driven into the ground, 20 yards or so distant from the observer, in such a direction that bearings of the objects from this stake coincide

with the bearings from North of the objects as found from the map. In other words, this stake marks the direction of the meridian through the position of the mast, the process being illustrated in Fig. 163.

This method is accurate to within 5′ of arc under favourable conditions, but there are certain precautions to be taken. If the objects upon which bearings are taken are nearer than about a mile, errors are likely to occur owing to the inability to locate accurately on the chart the position of the mast. With the object at one mile distant, an error of seven feet in fixing the position of the mast, introduces an error of 5′ of arc.

Although the average wireless D.F. cannot be operated to within an accuracy of anything approaching 5′ of arc, there is no excuse for slipshod work in the laying of the station, with the subsequent possibility of introduction of avoidable errors.

True North by the Prismatic Compass Method. Familiarity with the use of the prismatic compass is assumed, and the way in which it may be adapted to find the direction of the meridian in the case of the site of a D.F. station will present itself to the reader after noting the foregoing remarks on the same subject. The correction for magnetic variation can be found from Admiralty Charts or Ordnance Surveys, and it should be noted that the variation is not a constant for any given place, but the necessary correction for the annual change is generally given on the chart or map. It is advisable to use as recent an issue as possible, and not to exterpolate more than necessary when making this correction.

It is necessary to make certain that no iron or steel objects are brought near the compass during the time the readings are being taken, knives, keys, etc., being removed from the observer's pockets, and also care should be taken to ensure that the instrument is in good order and not sticking at all. Unless complete confidence can be placed in the compass to be used, this method of finding the direction of true North should not be adopted where any other is possible.

THE M-B-T SHORE INSTALLATION.

A shore D.F. station will usually take the form shown in Fig. 165, the two triangular frame aerials being supported at right angles to one another from a single mast at the centre of the system. There may be small masts to support the outer ends of the aerials with a view to stiffening them (Fig. 166), or these

four outer masts may be sufficiently high to give a diamond-shaped loop which will be less liable to be affected by the uneven nature of the ground on the site and also gives head room. Fig. 167 shows a square form of loop, in which four masts are used; but this is not in common use, owing to the cost.

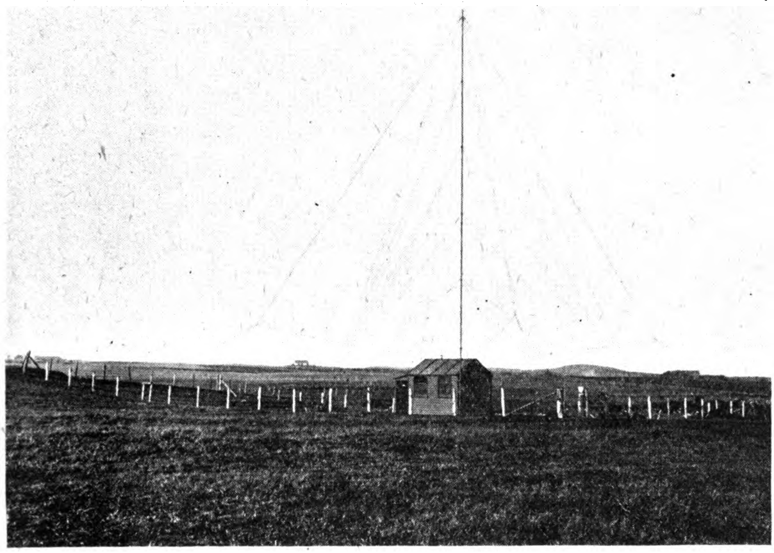


Fig. 165. *Triangular Aerials with Single Mast.*

Whatever may be the type of construction decided upon, the station consists essentially of two frame aerials at right angles, with leads running from the centre points of the base of the aerials to the receiving building, which is usually placed within a few feet of the aerials.

Laying Out the Site of a M-B-T Station. If a theodolite or sextant has been used for finding the direction of North at the site, the remainder of the work of laying out the positions for anchor stakes, etc., can be carried out very rapidly, and requires no further remark. If, on the other hand, no optical instruments are available, it is still a comparatively simple matter to lay out the site by the methods of field geometry. Right angles may be measured off by this means

to any accuracy desired, and the use of ranging poles for the purpose of alignment is one of the most accurate processes of surveying.

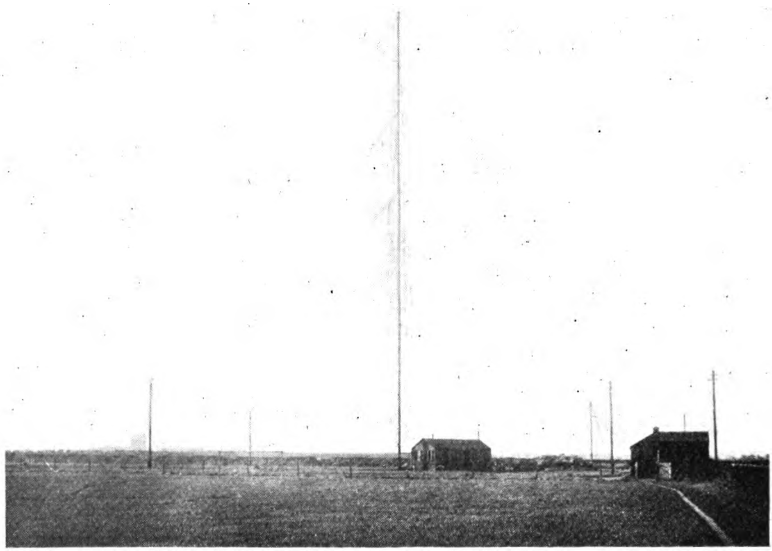


Fig. 166. *Triangular Aerials with Central Mast and Four Short Corner Masts.*

Suppose that in Fig. 168 stakes have been inserted at O and N, marking respectively the proposed position of the mast and the direction of North from the mast. Replace each of these stakes by a ranging pole (a straight wooden rod about seven feet long, an inch in diameter and having a point at one end for the purpose of sticking it into the ground). It will save further work if the distance O-N has been made equal to radius of the aerial anchors in the first place. Now measure off O-S equal to O-N, and insert a ranging pole at S in such a position that when the three poles N, O and S are viewed in line from a considerable distance, the near pole completely eclipses the other two. A small fraction of an inch error in the position of the pole at S is easily perceivable.

The direction of the line E W can now be found in several ways. From N and S arcs may be struck with a radius of $ON \times \sqrt{2}$ (*i.e.*, $1.414 \times ON$), which will intersect at the required points E and W; or use may be made of the fact that in a triangle the sides of which are in proportion 3 : 4 : 5, the 3 and 4 sides enclose a right angle.

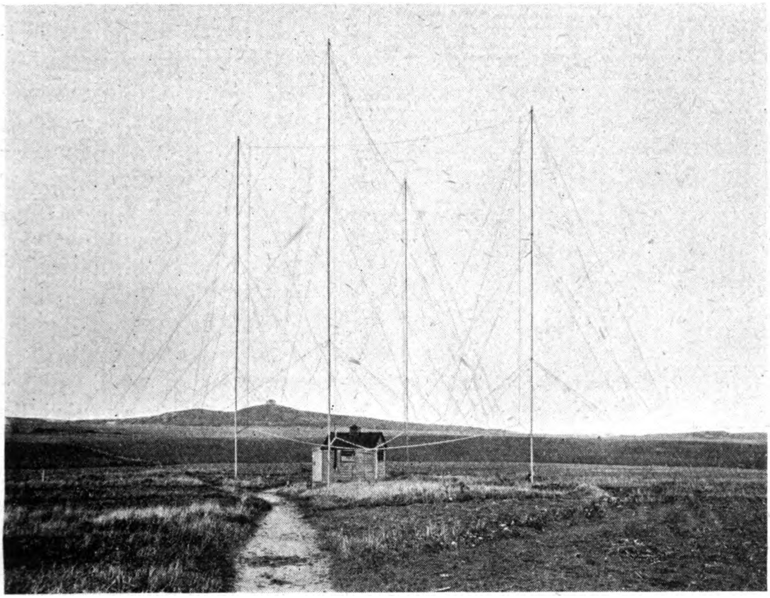


Fig. 167. *Square Aerials with Four Masts.*

These and various other methods of geometry are applicable and, having obtained the positions of E and W, ranging poles should be inserted at these positions and the line E O W inspected. If any discrepancy exists in the alignment, the process of measuring should be checked until the results are consistent. A site laid out in this way will have all the accuracy required.

The positions of the mast stay anchors present no difficulty. The angles between the aerials are bisected by measurement and ranging poles inserted at the correct radius for the mast stay anchors and checked for alignment. The same scrupulous care need not be taken in the case of the mast stays, except for large permanent stations, but care in the laying out of the aerials is well repaid.

AERIAL SYSTEMS: THEIR CONSTRUCTION, INSULATION AND METHOD OF SUPPORT.

Methods, more or less satisfactory, of rigging the two frames will probably present themselves to the reader who has had experience of the construction of any sort of aerials used in wireless work. Experience in practical direction finding work, however, shows that correct proportioning of the limbs of the aerials has a considerable effect on the results obtained with the installation, and some notes are given below on the dimensions and construction of the most common type of aerial used, namely, the triangular loop with the central mast 70 or 100 feet in height.

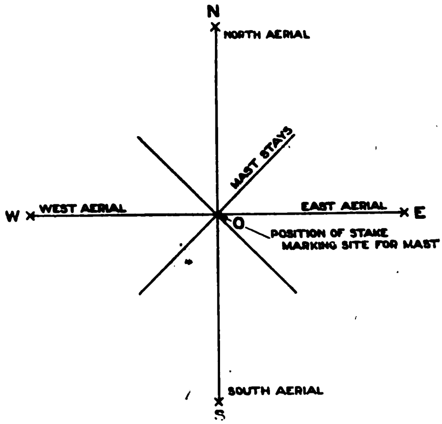


Fig. 168. *Plan of M-B-T Triangular Aerial System.*

Triangular Frames. A number of factors govern the height of mast to be used on a station, and the height of mast, in turn, governs the rest of the dimensions of the frames. If the range of the station is to be small, and particularly if the station be a temporary one, a 35 to 40-ft. mast will probably be used. For longer ranges and stations of a semi-permanent nature a 70-ft. portable mast is usual. Masts of 100 feet or more in height are generally permanent ones, and may be fitted with man halyards in order that the aerials may be rigged after the erection of the mast itself. The cost of the mast and the area of the site become great if high masts are used, and there is also a chance that the natural wave-length of the frames may be greater than the minimum wave-length to be received.

In Fig. 169 is shown a diagram of a triangular aerial, in which the proportions of the various parts are as follows :—

H=Total height of mast.

L=Length of outer limb of aerial.

B=Length of base limb of aerial=H or not less than $\frac{3}{4}$H.

h=Height of base at foot of mast=about 10′ or less in the case of a very small mast.

e=Elevation of base at outer end=12′ to 15′ or less in the case of a very small mast.

These proportions may be taken to represent average practice in the construction of triangular frames and, taking 70 feet as the height of the mast, the actual dimensions, structural and electrical, of the aerial system, would be as follows :—

Height of mast	70 feet.
Outer limb of aerial	90 ,,
Base limb	70 ,,
Height of base at foot of mast	10 ,,
Elevation of outer end of base limb ..	15 ,,

Total length of wire=2 (70+90)
=320 feet in actual frame.

In addition to this must be allowed 10 feet at the top of the mast for the cross-over and, say, 12 feet for each of the leading-in wires to the receiving room, so that the total length of wire required for each aerial is 320+(2×12)+10=354 feet.

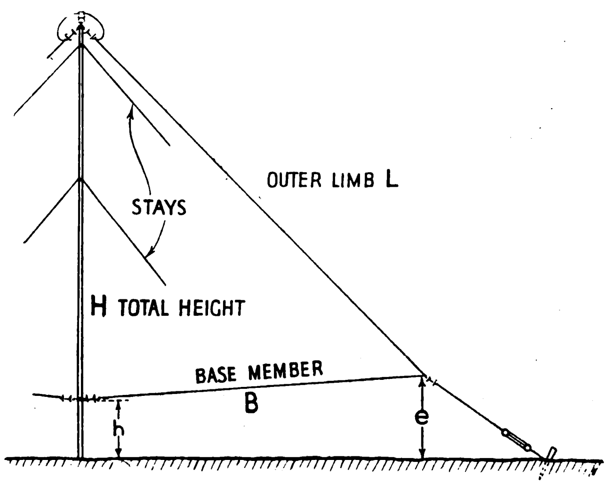


Fig. 169. *Proportions of Triangular Aerial.*

The natural wavelength of such an aerial is between two and two and a half times the length of wire in the loop. In the example taken above the length of wire is $320 \times 0.3048 =$ 97.5 metres, whilst the measured wavelength was found to be 233 metres or $\frac{233}{97 \cdot 5} = 2 \cdot 39$ times the length of wire in the frame.

Other electrical constants of the aerial are :—

Inductance of each loop	164 mhys.
Capacity to earth of complete aerial ..	0.0017 mfd.
Low-frequency resistance of each loop when aerial made of 7/19 silicon bronze wire ..	0.65 ohm.

Construction of Aerial. Each frame should be made of a continuous length of wire, which has no soldered joints. This is desirable, not only from the aspect of mechanical strength, but also because any joints which are not quite perfect may increase the resistance of the loop in which they occur and give rise to out-of-balance effects. For the same reason the wire of each frame should be of the same material and gauge.

Any standard aerial wire is suitable for D.F. work, such as 7/19 or 7/22 silicon bronze. Although the span is rarely more than a fraction of the span between the supports in the case of the wires of a large transmitting or receiving aerial, still a strong wire is desirable, owing to the necessity of pulling the frames very taut after erection, in order to prevent swaying in the wind, with consequent production of mutual inductance or variation in the strength of signals.

A convenient way of measuring off the aerials is shown in Fig. 170, which ensures the dimensions of all corresponding

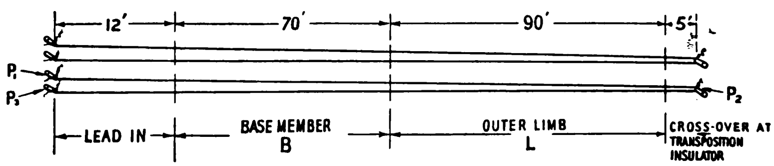


Fig. 170. *Simple method of measuring off wire for Triangular Aerials.*

limbs being identical. Pegs P_1, P_2 and P_3 are driven into the ground on a level part of the site at distances apart determined by the dimensions of the aerials decided upon. One end of the wire is made fast to P_1 and the other to P_3, the bight

having been taken round P_2. The other aerial is pegged out in the same way alongside the first, and the lengths of the various parts of the loops are measured off and a seizing placed round the wires at each point where a thimble has to be inserted.

Provision must be made at the masthead for supporting the aerial cross-over insulator and also the strain insulators for the outer limbs of the frames. Fig. 171 shows a form of construction in which the two frame aerials are supported by porcelain strain insulators, whilst the apexes of the loops are insulated from one another by means of a telegraph transposition insulator which is either fitted to a mast cap or to a spindle which is screwed into the top of the mast. An annular mast-cap fitted with four eyes is used to support the outer limbs of the aerials, the insulators of which are shackled to the mast-cap as seen in the illustration.

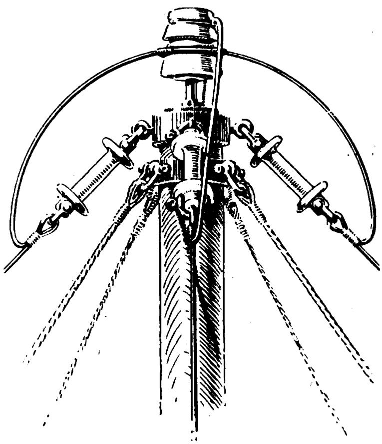


Fig. 171. *Masthead arrangement of Triangular Aerials.*

If the mast is a light one and not fitted with a man halyard, all this gear must be fixed before the mast is erected, and a good deal of care is necessary to ensure that nothing fouls in the process.

Fig. 172 shows the method of tying back the ends of the base and outer limbs of the aerials. The rope halyard may be

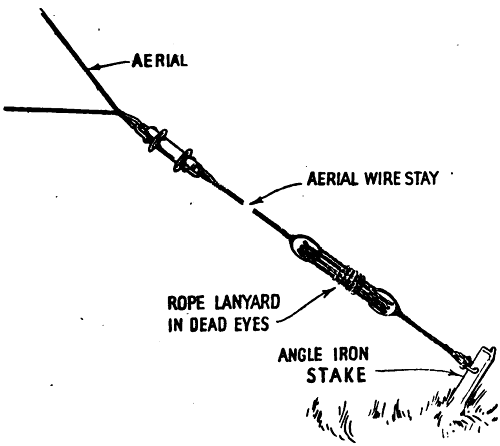


Fig. 172. ***Method of Anchoring Triangular Aerial.***

replaced by a rigging screw (turn-buckle) if desired ; but the aerial wire has a good deal of stretch in it, which means constant re-splicing of a wire stay. Apart from this, the occasion hardly warrants a rigging screw. The aerial should never be stayed back entirely with rope, even if it be tarred, as there will always be a certain amount of shrinkage when it becomes wet, and trouble due to slackening during a dry spell.

An alternative method of securing the outer ends of the aerial is by means of a small mast. This allows a larger aerial to be rigged on the same area, and also reduces the swaying in the wind. In the case of the diamond-shaped aerials, the outer masts become almost essential.

The diamond-shaped loop is not in general use except on stations which are built on very uneven ground, in which case, if the triangular aerial were used, the difference in capacity between the earth and the respective base limbs of the frames would seriously affect the bearings.

Good insulation, especially with tuned aerials, is very necessary, and it is advisable to use porcelain throughout if possible. The "dumbell" form of porcelain insulator illustrated in Fig. 171 is a very satisfactory one, and an aerial constructed with these will usually have an insulation resistance of 10 megohms under adverse weather conditions. Porcelain cannot be used in the case of portable stations, as the breakages are too great during construction, and, in this case, an ebonite rod makes a good substitute.

Leading-in of the Aerials. The way in which the aerials are led from the foot of the mast to the receiving building will vary according to the type of station, and one of the best methods of leading in when using tuned aerials, is as shown in Fig. 173. In making the aerials, enough "tail" is left to enable the lead-in to be a continuous length of wire with the aerial loop itself and telegraph insulators are used for the support.

If, for some reason, it is not possible to arrange a short lead-in, intermediate supports will be necessary as in Fig. 174, which shows three of these posts and the lattice steel mast supporting the aerials. It will be seen that the four insulators on each post are arranged so that the points of attachment of the wires form a rectangle and it is important that the two wires for any pair of leads should be at *diagonally opposite corners* of this rectangle. If, on the other hand, one pair of

leads are attached to the top two insulators and the other pair to the lower ones, the planes of the small frame aerials, represented by the pairs of leads, will be parallel for a considerable distance and very appreciable coupling will exist between the aerial circuits.

The diagonal arrangement, however, does not eliminate all coupling unless the insulators are fixed in an exact square; for

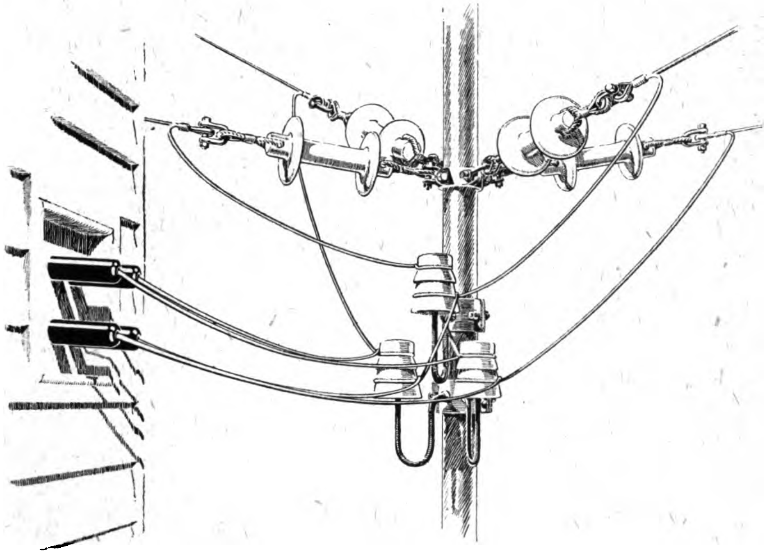


Fig. 173. *Short Lead-in for Tuned Aerials.*

only in this case are the planes of the two loops exactly at right angles to one another. A closer inspection of Fig. 174 will show that the four leads are rotated or **transposed** along the length of the lead-in, the wire from the top right hand insulator on the near post going to the bottom right-hand insulator on the second post and to the bottom left-hand of the third post, etc; and similarly with the remainder of the leads. The result of this transposition is that if one complete revolution (or any number of complete revolutions) be made between the foot of the mast and the receiving room, any coupling which is introduced between the pairs of leads at one section, is neutralised by an equal and opposite coupling at some other section.

Another important reason for transposition is to prevent the direct reception, which would take place if the pairs of leads

ran in the same respective planes throughout the full length. Owing to the rotation of the wires it follows that any E.M.F. induced in one of the loops (formed by the pair of wires from one of the aerials), will be opposed by an equal E.M.F. induced in another section of the same loop which is in the opposite direction *round the circuit*. This type of transposition is

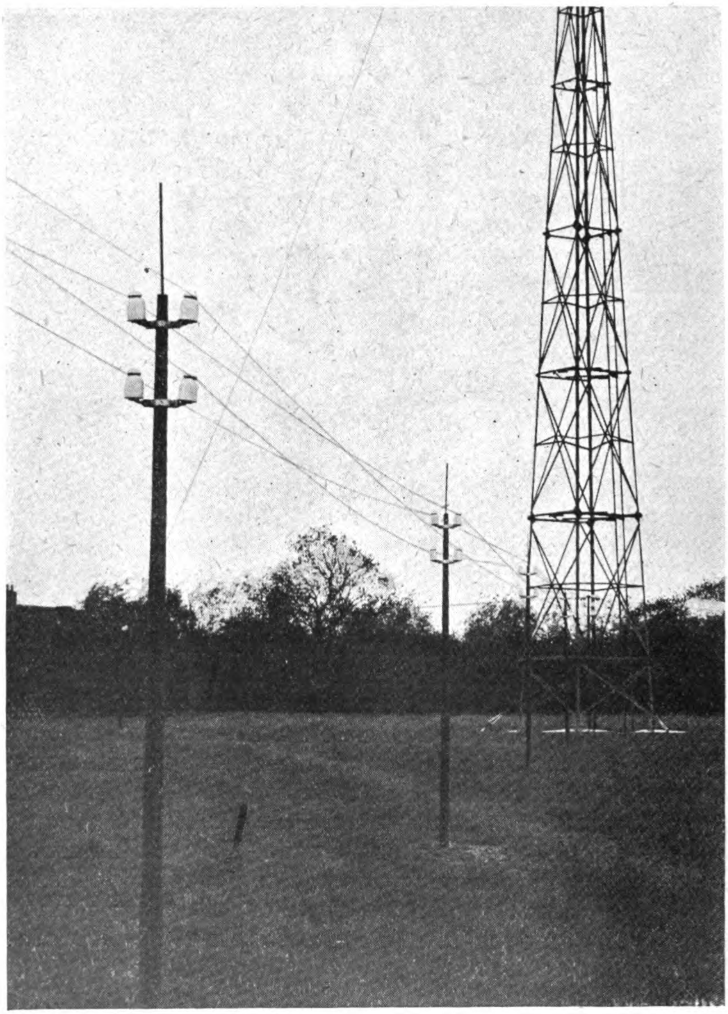


Fig. 174. *Long Lead-in, showing Transposition.*

adapted from telephone practice where it is used to prevent interference from other circuits.

Yet a third advantage of transposing the wires of the lead-in is that the mean distance from the ground of all the four wires is now the same, and hence the capacity of the four wires to earth is constant. This has the effect of maintaining the electrical balance of the aerial circuits which has been seen (Page 55) to be an important factor, especially in the tuned aerial system.

The wires should be strained sufficiently tightly to prevent swaying in the wind, with consequent production of mutual induction or capacity between the loops, and for the same reason they should not be run too near to one another as in this case the relative movements of the wires will have a proportionately greater effect. Between six inches and a foot is a suitable dimension for the horizontal or vertical distance between wires.

It is advisable not to take the strain of the last section of the lead-in on insulators attached to the wall of a wooden receiving building, or trouble may be experienced owing to the noise, made by the vibration of the mast and aerials in the wind, being transferred to the receiving room.

The insulators used should be of a similar pattern throughout, otherwise the varying leakage resistances of the insulators in wet weather may result in the two aerial circuits having different dampings.

With the aperiodic aerials many more liberties can be taken and with a 70 or 100 foot mast and triangular aerials, a lead-in of the form shown in Fig. 174 may be 50 or 75 feet in length and still give perfectly satisfactory results. In the case of the temporary station, high tension cable of the type used for the ignition systems of petrol engines may be used in an emergency, thus dispensing with all further insulation between the aerial base and the D.F. receiver. Such an arrangement is illustrated in Figs. 175 and 208. Twin wires enclosed in lead sheathing are used in the ship installation and this is described in the next chapter. Cases may occur in shore D.F. stations where the use of this lead-covered cable is of use for a lead-in but it can only be used with aperiodic aerials.

The problem of the best way to take the wires through the wall of the receiving building has been tackled in many ways, but the best results are obtained by taking the aerial wire through an earthenware or porcelain tube, tilted downwards

towards the outside and the ends of which are suitably protected from the weather. A view of such an arrangement for the four aerial wires is shown in Fig. 173.

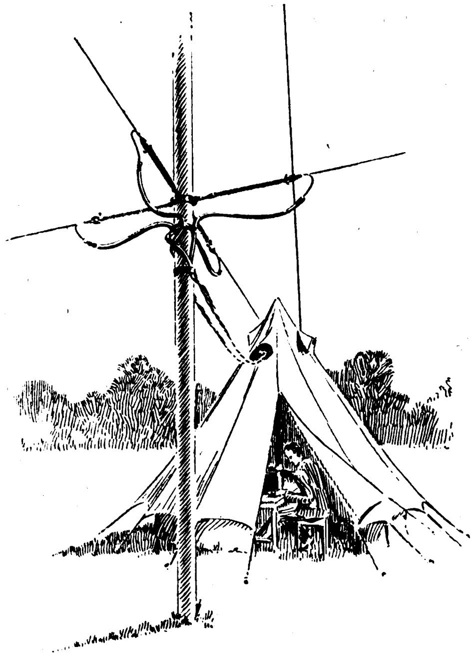


Fig. 175. *Temporary Lead-in for Aperiodic Aerials.*

If desired, a partition insulator of some type may be used, and it has the advantage of being capable of being made weather-proof, but possesses the great disadvantage that it introduces four dry connections in each aerial lead. It may be wondered that apparatus which has stood the test of constant use for years on the ordinary wireless receiving station is criticised or condemned when applied to direction finding work. The reason, however, is that if a high resistance fault occurs on an ordinary receiving station, this fact at once makes itself apparent by the weakening of signal strength, whilst on a D.F. station the signals in one frame become weaker than in the other, the " minimum " as heard in the telephone becomes first indefinite and then definitely wrong. If bearings are not being taken during the indefinite period the trouble may not be suspected for some time, and before noticing the errors in bearings a station in use for coastal work might easily be the unwitting cause of wrong information being given to ships concerning their positions.

For this reason the sight of the four actual ends of the wires which compose the aerials, attached to the radiogoniometer or the aerial disconnecting switches, and the knowledge that these wires are supported throughout by a good design of porcelain telegraph insulator, inspires a good deal of confidence

and reduces the chances of trouble outside the receiving room to a minimum.

Position of the Receiving Building. The position of the receiving building relative to the mast and aerials is fairly important. If the building be long and narrow and placed very close to the aerials and parallel to one of them, then there will be a greater capacity between the building and the aerial which lies parallel to its length than there is in the case of the other aerial, and, in addition to this out-of-balance effect, there will also be a capacity coupling between the two frames which will make itself evident when the test is made for mutual induction and capacity. It is possible to eliminate this capacity coupling caused by the building by connecting a small variable condenser across the two limbs of the aerials opposite to those which enclose the building, the condenser being adjusted until a balance is obtained giving a nil result when testing for mutual. (Page 238.)

Dielectric losses will also occur if the walls of the building are too close to the aerial, and unless the building be a square one these losses will not be equal in both aerials.

It is therefore advisable, in the case of tuned aerials, to choose such a position for the mast that they are between two and three feet away from the walls of the receiving building, which will give a short lead-in and will yet reduce the above-mentioned errors to a negligible amount. When dealing with the aperiodic aerial installations on board ship it will be seen later that a lead of a hundred feet may sometimes be necessary, but for accurate shore work the lead-in should be as short as possible.

The Earth System. No departure is necessary in respect to the earth system from the methods adopted for the non-directional wireless receiving station, and the standard practice is to make use of a circle of galvanised iron plates, buried in the ground at a radius of about 10 to 20 feet, the plates being in a vertical position and soldered to one another, or to radial wires brought to an earthing bus-bar inside the receiving building.

In the case of temporary stations, the wire gauze nets used for portable field wireless sets are satisfactory, and it is usual to put one length of gauze under each of the four lower limbs of a Bellini-Tosi aerial.

RECEIVING APPARATUS.

Special instruments are used in direction finding work which are not met with in the ordinary receiving station. Chief among these are the radiogoniometer, shielded transformer, D.F. wavemeter and the aerial tuning buzzer.

The Radiogoniometer. This instrument is, of course, common to all M-B-T stations, no matter what the remainder of the circuit may be; but the design of the radiogoniometer varies according to whether the system is operating with tuned aerials, simple aperiodic aerial circuit or the combination of frame and open aerial circuit adapted to the determination of sense.

Shore Pattern Radiogoniometer (Tuned Aerials). Fig. 176 shows one method of mounting the field coils and

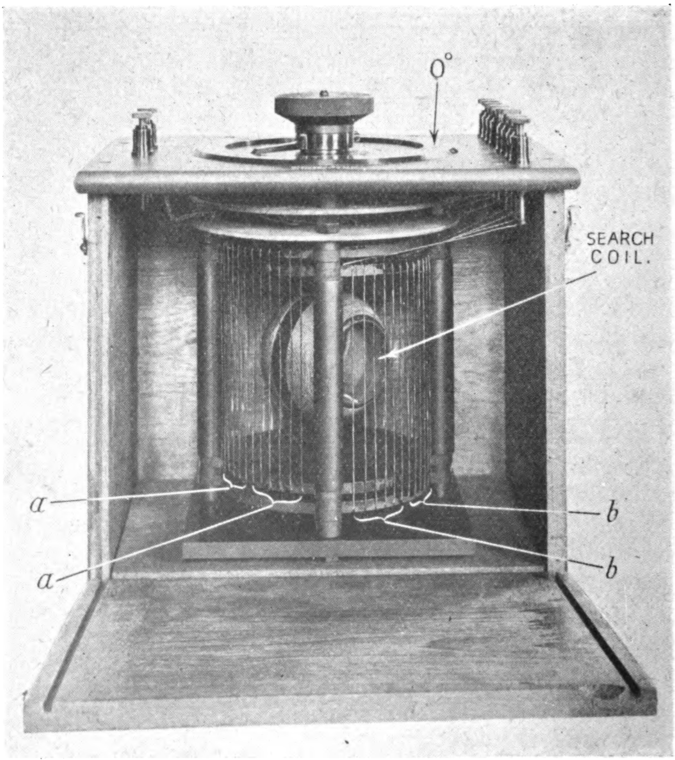


Fig. 176. *Radiogoniometer for use with Tuned Aerials.*

search coil of a radiogoniometer of fairly large dimensions for shore use. *a*, *a*, and *b*, *b*, are the two sets of field coils, each of which is broken at the centre of the winding and has leads taken to terminals for the insertion of the aerial tuning condensers. The framework on which the coils are wound is of ebonite.

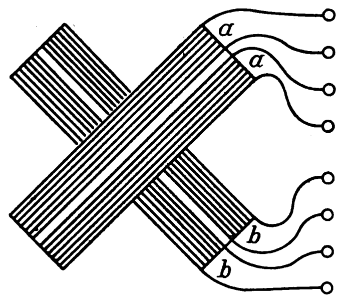


Fig. 176*a*. *Field Coil Connections*

The search coil is wound on a spherical ebonite former, the leads being brought out to a pair of terminals on the top of the instrument. A device is fitted in this particular design to prevent the search coil making more than three complete revolutions, and thus preventing undue strain being put on the flexible leads. (In some designs, slip rings are fitted, allowing unlimited rotary motion of the search coil.)

This type of instrument having a loose coupled spherical search coil is always used with "tuned aerials," and since the efficiency of the tuned aerial reception is high and the coupling of the field coil and search coils is small, there is no necessity for the use of a shielded transformer.

Shore Pattern Radiogoniometer (Aperiodic Aerials). (Fig. 177.) In this case the field coils are seen to be almost the same as in the previous instrument, but the search coil is cylindrical in shape and is much more tightly coupled to the field coils. This type of radiogoniometer may be used either with tuned or aperiodic aerials, but owing to its comparatively tight coupling, a shielded transformer is advisable in the former case and essential in the latter. (See page 62). It is customary in the case of aperiodic aerial working to make use of a radiogoniometer which has a coupling of not less than 50 per cent., for reasons which have been stated on page 57.

Modifications in the above designs are necessary in the case of ship or aircraft installations, or when the radiogoniometer is to be used with the heart-shape circuit for sense determination, and further reference to these instruments will be found on pages 248, 282 and 308.

Points in the Design of the Radiogoniometer. Like a large amount of other wireless apparatus, the radiogoniometer was designed in the early days rather on a "hit and miss"

principle, and at the present time the electrical constants vary considerably according to the type of circuit with which the instrument is to be used, and few hard-and-fast rules can be given as to the design.

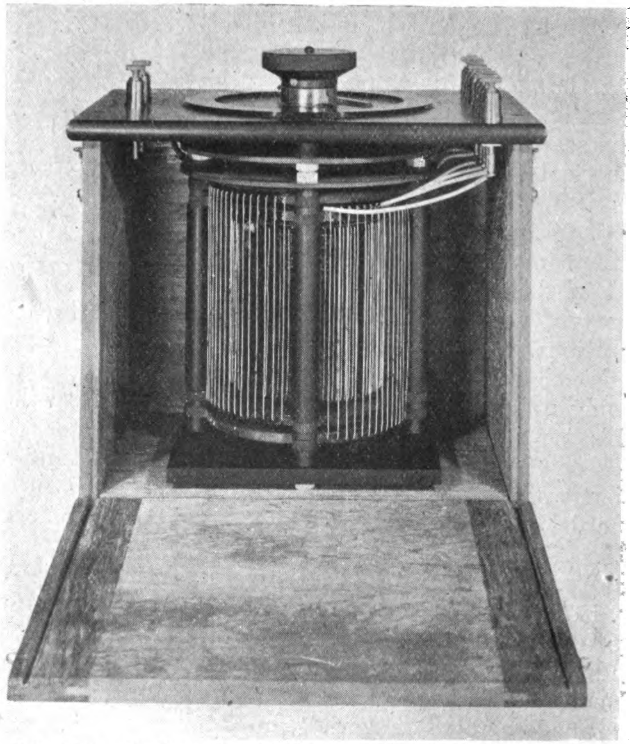


Fig. 177 *Radiogoniometer for use with Aperiodic Aerials.*

It is usual to make the leakage inductance of the radiogoniometer and search coil circuit approximately equal to the inductance of the aerial loops, for if it differs much from this value the coupling between the field coils and search coil will be reduced. A large inductance of field coil increases the minimum wave to which the system can be tuned, and also introduces greater leakage in the transformer represented by the field coils and search coil.

The dimensions and inductance of the search coil depend on the wavelength range of the instrument and also the coupling desired. With tuned aerials the coupling may be very loose, and the smaller the search coil is made the greater will be the

accuracy of the instrument, owing to the fact that the search coil is rotating in a more uniform field than exists close to the field coils.

The limit in reduction of size is reached when the coupling becomes too small.

With aperiodic aerials the coupling usually is made as tight as possible and is as much as 80 per cent. in the radiogoniometer, shown in Fig. 220. In this case a coupling error of between 2° and 3° would exist if a simple search coil were used, and it is therefore wound with two coils spaced 45° apart and connected in series, reducing the error to within practical limits in the manner already described on page 61.

The D.F. Wavemeter and Tuning Buzzer. This

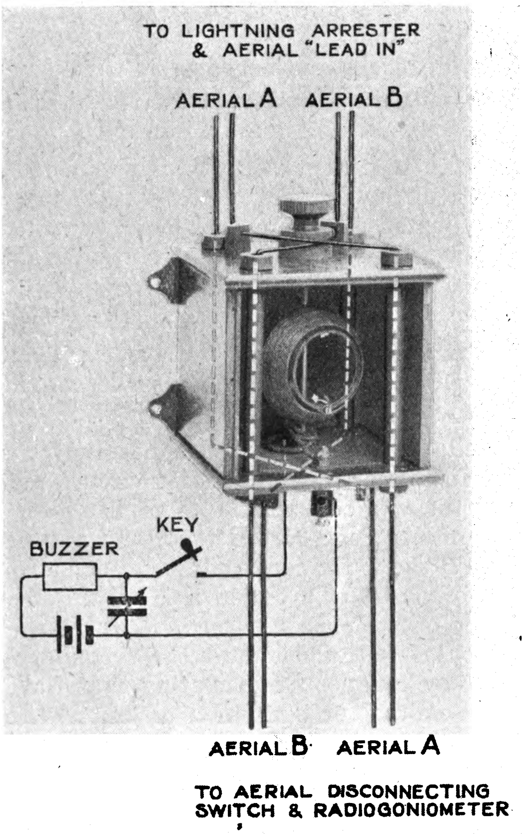


Fig. 178. *D.F. Wavemeter and Tuning Buzzer.*

apparatus, which is only used in connection with the tuned aerial circuit, is shown in Fig. 178. It consists of a box, in the centre of which a winding on a spherical former is arranged so that it may be rotated about a vertical axis. At the corners of the box four vertical ebonite tubes are fixed, through which the aerial wires are taken at some point between the lead-in and the radiogoniometer. This type of construction is adopted in preference to terminals and aerial windings on the instrument, with a view to reducing the number of screwed connections in the aerial circuits. Each aerial lead is seen to make half a complete turn round the box, enabling the aerials to be coupled to the tuning buzzer circuit. This geometrical arrangement of the aerial leads complies with the following requirements of the tuned aerial system :—

Symmetry of aerials.

Equal length of leads and hence equal resistances.

Absence of mutual inductance between aerials (except by means of the spherical wavemeter coil).

The moving coil, together with a variable condenser, forms an oscillatory circuit, which is excited by means of a battery and high-note buzzer, the circuit being calibrated over a range of wavelength on which the D.F. station is intended to operate.

An important detail is that the buzzer switch is placed in the oscillatory circuit and not in the battery lead, so that during the reception of outside signals the moving coil is disconnected and does not couple the aerials.

The Shielded Transformer. The necessity for the use of a shielded transformer in the receiving circuit, more especially when using the aperiodic aerial system, has been explained in Chapter 2, and on Page 35 the theory of the action was discussed. Fig. 179 shows the construction of such a transformer and it is seen to consist of a cylindrical former of ebonite or similar material, on which are placed, in turn, the primary winding, the copper-foil shield and the secondary winding, each separated by a layer of insulating material, which is usually "empire cloth" or paraffined paper.

The shield extends beyond the ends of the windings to a distance of about ¼ to ½ inch, and in order to prevent it forming a short circuited turn a strip of insulation is placed along the length of this foil where the overlapping takes place.

On page 65 it was said that in the combination of the aperiodic aerial and resistance phased heart-shape diagram of reception the apparatus was sometimes simplified by omitting the intermediate circuit and using a shielded transformer, which, by means of a tertiary winding, combined the loop and vertical wire aerial E.M.F.s in the required manner.

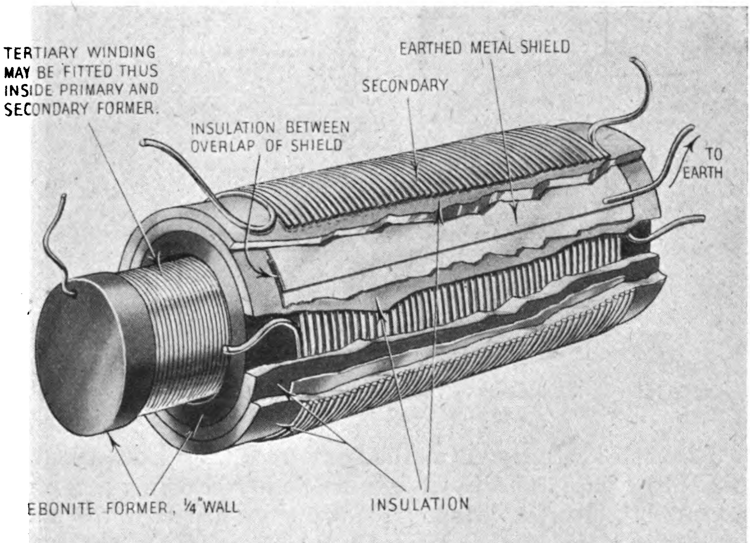


Fig. 179. *Shielded Transformer with Tertiary Winding.*

A method of mounting this tertiary winding on a second ebonite former is shown in Fig. 179. This former slides in flush with the other windings and the whole transformer may be mounted up as shown in the case of the transformer panel of Fig. 222.

The "reaction" method of receiving continuous waves has been referred to on page 84, in which a coil is connected in series with the filament and grid of the rectifying valve of the amplifier and arranged so that this coil can be coupled back to the receiving jigger or some other inductive part of the receiving circuit. Such a reaction coil is fitted in the double range shielded transformer shown in diagrammatic form in Fig. 180, and has a tapping in the winding with change-over switch for use on long or short wavelengths. An external view of the same apparatus is shown in Fig. 181, and it will be noticed that a metal screening case encloses the whole instru-

ment, this being provided to reduce the direct reception of signals on the coils of the transformers and also to stabilise the circuit by reducing the inductive or capacity coupling between various parts of the apparatus, where such couplings are undesirable.

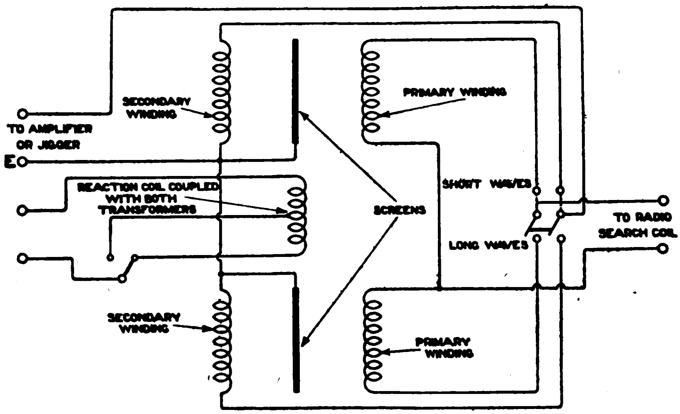


Fig. 180. *Connections of Double Range Shielded Transformer with Reaction Coupling (see Fig.* 181.)

The self-heterodyne method of reception described on page 87, has an advantage in rapid searching; there is, however, the disadvantage already mentioned that the note is slightly affected by variation in coupling of the radiogoniometer.

Some Points in the Design of the Shielded Transformer. It is found that the shielding effect is better if the ratio $\frac{\text{length}}{\text{diameter}}$ of the transformer windings be kept within the limits 2.5 to 3.5. If the length and diameter be made approximately equal, then the shield will have to be extended considerably beyond the ends of the windings, involving an unnecessary amount of eddy current loss in the copper foil. It is usual to make the inductance of the primary winding of about the same as that of the search coil, and both these values are largely governed by the wavelength of the circuit and the coupling which is desired in both the radiogoniometer and the transformer.

The coupling between the two windings is always made as tight as possible to avoid leakage and consequent loss of signal strength, although if the insulation between the windings

be made very thin the self-capacity of the transformer may become so great that tuning on low wavelengths becomes extremely flat or altogether impossible. The range of wavelength covered by the transformer in conjunction with any given tuning condenser also becomes very restricted. A compromise has therefore to be effected, and the thickness of the insulation will generally be in the neighbourhood of $\frac{1}{16}$ to $\frac{1}{10}$ of an inch.

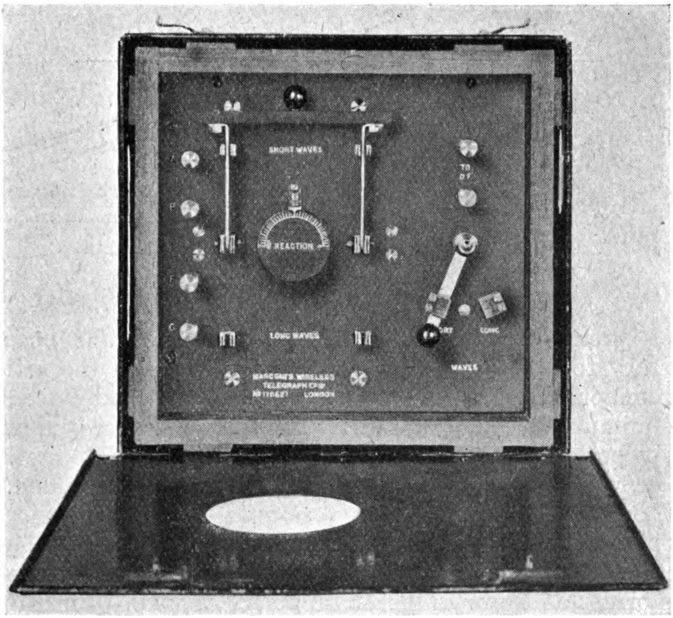


Fig. 181. *Front View of Shielded Transformer* (*see Fig.* 180).

The way in which the wavelength range of an oscillatory circuit is affected by the capacity of the (supposed) inductive portion of the circuit is shown diagrammatically in Fig. 182, where L_1 and L_2 may be considered as the primary and secondary of a transformer and C a condenser of low capacity in parallel with the latter. The capacity between the windings of the transformer and the self-capacity of the secondary L_2 are represented by the small dotted condensers, and the effect upon the tuning of the circuit will be the same as if a fixed condenser had been put in parallel with the condenser C.

By careful design and proportioning of the various parts of an aperiodic circuit it is possible to get a range of wavelength

of about $2\frac{1}{2}:1$ or $3:1$ with a given transformer. This means that if the tuning condenser in the secondary circuit be set at the lowest value at which definite resonance is obtained, and the wavelength then is, say, 300 metres, the wavelength obtained with the maximum value of the variable condenser will be about 900 metres. This ratio will depend, of course, upon the maximum and minimum values of the condenser, but the above is a rough rule.

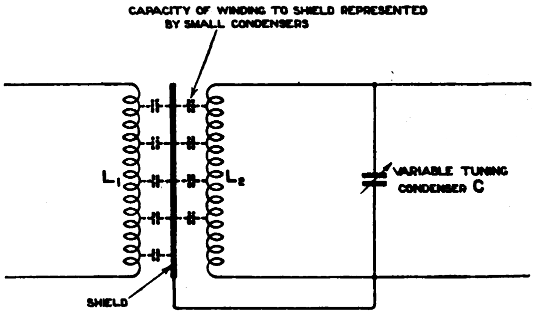


Fig. 182. *Effect of Capacity of Transformer Windings.*

If a greater range of wavelength is required, it becomes necessary to have a second transformer in which the ratio of the number of turns on the two windings is so adjusted that the minimum wavelength on the second transformer is approximately equal to the maximum wavelength of the first. A further range of 900 to 2,700 metres will then be obtained.

In order to obtain a large potential for operating the amplifier it is usual to keep the value of the air condenser, which is connected across the secondary of the shielded transformer at a low value of capacity, say 0.0016 maximum and about 0.00004 minimum. For long wavelengths this necessitates the transformers being lap or pile wound to increase their inductance.

LAY-OUT AND ADJUSTMENT OF RECEIVING APPARATUS.

Three types of direction-finding circuit were dealt with in Chapter 2 when describing the M-B-T system. These are as follows:—

(1) Tuned aerials.
(2) Aperiodic aerials.
(3) Aperiodic aerials with loose-coupled intermediate circuit.

Both (2) and (3) can be adapted to the practical determination of "sense."

Whichever system be in use, all the usual precautions associated with the laying out of a wireless receiving circuit must be observed, and in addition to these, there are a number of further precautions which are described below.

TUNED AERIAL CIRCUIT.

The theory of the action of the tuned aerial circuit is explained on page 56, *et seq.*, and the circuit is shown in Fig. 35. Fig. 183 shows the lay-out of a tuned aerial D.F. receiver from which the appearance of the actual apparatus can be gathered.

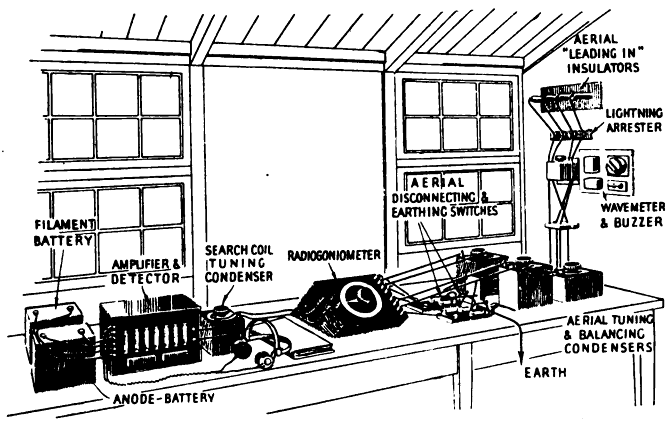


Fig. 183. *Lay-out of Tuned Aerial Circuit.*

Lightning Arrester and Earthing Switch. The installation of the circuit, as far as the leading-in insulator, has already been considered, and on entering the receiving room the aerials are usually connected to a lightning arrester or an aerial earthing switch, or both these pieces of apparatus. They are intended to safeguard the receiving gear from the effect of "fizzlies," or atmospheric discharges from charged clouds. Neither of them would afford any appreciable protection if the aerial were actually struck by lightning, which has been known to wreck totally the apparatus in a receiving station, and requires protective devices on a far larger scale. The lightning arrester mentioned above consists only of an ebonite strip on which are mounted four terminals to which the aerials are attached. Each of these terminals is connected

to one side of a spark gap of about $\frac{1}{2}$ m.m. the other side of all four gaps being connected to earth.

Wavemeter and Tuning Buzzer. The best position for the wavemeter and tuning buzzer is immediately below the lightning arrester and close to the lead-in. In this position it can usually be placed as far as possible from the remainder of the receiving apparatus, and there will be less chance of the exciting circuit inducing an E.M.F. in the coils of the radiogoniometer, the transformer or the amplifier.

Aerial Disconnecting Switches. Between the wavemeter and the radiogoniometer, aerial switches are placed, which enable the rapid disconnection of either aerial during the process of tuning and balancing. The exact use of these switches will appear later.

Wiring of the Circuit. From the lead-in to the radiogoniometer the wiring should be supported on insulators spaced at short intervals, and the greatest care taken that the wires of the aerials are spaced at least two or three inches apart and symmetrically arranged so that mutual inductance between the pairs of leads is as small as possible. It may be found necessary to make provision for a small amount of mutual inductance between the aerials to counteract an equal and opposite amount elsewhere in the aerial circuit, but this need not be anticipated and the whole of the wiring should be arranged rigidly.

It is very inadvisable when connecting up the apparatus of wireless receiving apparatus, and more particularly of a direction-finding installation, to run any wires through the bench, cleating them along underneath and then bringing them out on the surface again alongside the instrument to which they are to be connected. In exceptional cases, where this is necessary, the holes in the bench should be about two inches in diameter, so that the wire is kept well clear, and it should be supported so that the wire does not come into close proximity to portions of the bench or other woodwork or the walls of the room.

The reason for these precautions in D.F. work is that the dielectric losses in the bench, the walls of the room, etc., may cause unequal damping in the aerials, with consequent production of bad minima, and furthermore, the capacity between the aerial leads and the bench is quite enough, particularly on wavelengths below 600 metres, to give capacity coupling

between the aerials. On longer wavelengths the effects are not so marked, but the point is worth bearing in mind.

The Radiogoniometer. The radiogoniometer should be fixed in such a position that it can be easily manipulated and at the same time leaves space for writing. This space should not be between the radiogoniometer and the "lead-in," otherwise the aerial leads will have to be unnecessarily long and either run under the top of the bench or along the back of it. In either case there is the chance of variable capacity coupling between the aerials owing to the log-book, operator's arm, etc., constantly moving near the aerials.

The orientation of the radiogoniometer and the angle to which it is tilted for convenience in reading have no effect, or almost negligible effect, and it may with advantage be sunk in the receiving bench and slightly tilted forward.

On page 320 some notes are given on the precautions to be taken in connecting up the aerials to the radiogoniometer and the methods of diagnosing the errors which occur owing to wrong connections having been made. The correct connections will usually be indicated on the radiogoniometer, but in case this is not so, the above-mentioned notes will give all the information necessary.

Aerial Tuning Condensers. On all except very long wave sets the aerial tuning condensers will be air dielectric, the limiting factors being the size and cost of large air condensers. They are connected up, one in series with each pair of field coils, the latter being split for the purpose and leads being brought to terminals on the radiogoniometer. In Fig. 176 these terminals are the second and third, and the sixth and seventh of the row on the right-hand side of the top of the instrument. In parallel with one of the aerial condensers is a third condenser of about one-tenth the capacity of the others, which is used to obtain a fine adjustment when balancing the aerials. Thoroughly good electrical connection must exist between the vanes of each set, fixed and movable. Any variable contacts here will render accurate balancing impossible. The leads from the radiogoniometer to the aerial condensers form part of the aerial circuit, and the same care should be taken here to avoid mutual induction between them. For this reason the radiogoniometer and the condensers must be fixed to the bench, or trouble is almost bound to arise from the above cause.

The space for writing materials, etc., may conveniently be left between the radiogoniometer and the shielded transformer if one be used, as the leads from the search coil to the receiving circuit may be run as a twisted pair of flexibles. There is also the advantage in this form of lay-out that coupling of the radiogoniometer with the transformer and amplifier is avoided.

No special precautions are necessary in the arrangement of the remainder of the apparatus, except that the screening boxes of the amplifier and shielded transformer are usually earthed in order, as far as possible, to prevent direct reception. The radiogoniometer may be screened for the above reason, as in the case of the ones illustrated in Figs. 190 and 218.

The question of to what extent the apparatus should be connected to earth depends rather upon circumstances, but it is usual to earth the negative terminals of filament and plate circuit batteries. On certain wavelengths, however, it may sometimes be found that the minima are sharper if the transformer shield and the "B" terminal of the amplifier be earthed instead of the batteries. The point may easily be settled by trial, and if an advantage is gained by not earthing the common negative, it will frequently be found an additional improvement to insulate the batteries, as if standing on the floor of the room they may otherwise be forming a leaky capacity connection to earth.

Reception of Continuous Waves by Means of Separate Local Oscillator. The chief precaution to be observed when using a separate heterodyne for C.W. reception is to ensure that it is not coupled with the radiogoniometer, for, in this case, trouble will ensue owing to the heterodyne signals having a definite direction of their own and producing another pair of minima. The most satisfactory methods are to couple the heterodyne either to the amplifier or the transformer, or, in the case of a loose-coupled intermediate circuit, a special provision may be made for coupling the heterodyne to the jigger secondary, as shown in Fig. 196. A method sometimes adopted is to employ a coupling in series with the anode battery of the amplifier.

In any case, the coupling of the heterodyne must not be sufficiently tight to cause a wipe-out of the received signals, owing to the saturation of the rectifying valve, etc.

Tuning and Balancing. The apparatus having been connected up, the next process is that of tuning the whole circuit and balancing the aerials.

During the tuning and balancing process the magnification of the amplifier should be reduced to a low value, either by cutting out valves in the case of a cascade amplifier, or by some other similar process, until medium strength signals are heard. If this is not done it may be found difficult to balance, owing to noise caused by direct induction in the transformer and the D.F. search coil from the exciter circuit.

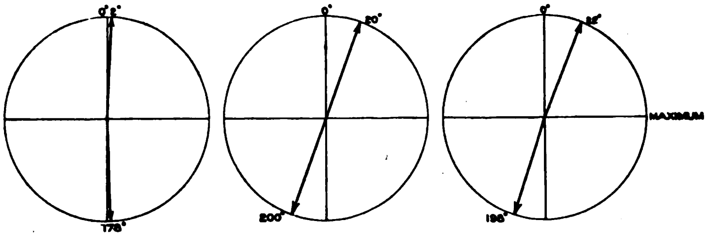
Adjust the aerial tuning buzzer to the required wavelength and rotate the moving coil of the wavemeter to some portion intermediate between the planes of the two aerial turns.

Disconnect one aerial and tune everything up to buzzer wavelength, then disconnect the tuned aerial and connect the other, again tuning to buzzer wavelength, and for this purpose it should not be necessary to alter anything except the aerial condenser.

In doing the above tuning the coupling of the radiogoniometer should be kept loose, *i.e.*, the search coil is nearly at right angles to the field coil of the aerial in circuit. When both aerials are tuned, close both the aerial switches and turn the pointer to the position of minimum signals. In the case of a D.F. wavemeter which has a rotating coupling coil, the position of this minimum will depend upon the position of the coupling coil relative to the aerial turns, but should always be adjusted, as stated above, to some position intermediate between the two. Now adjust one of the aerial tuning condensers (the low capacity one if fitted for fine adjustments) until the best minimum is obtained, slightly varying the position of the pointer of the radiogoniometer during the process if necessary.

To Check the Circuit for "Vertical," "Direct" and "Mutual." In the above instructions for tuning and balancing it was assumed that the circuit was free from vertical and direct, and that the radiogoniometer was in correct adjustment. These points should be checked in the following manner. As each aerial is tuned, take scale readings of the minima, to ensure, firstly, that the two minima are exactly opposite one another on the scale, and secondly, that they coincide with the 0°—180° line or the 90°—270° line, according to whether the North-South or the East-West aerial is in circuit (it is assumed that the aerials have been laid out in the above manner), or, thirdly, that there is not a combination of both these errors.

As an example of the first error, let us assume that the N-S aerial is connected, and that the minima, instead of being at 0° and 180°, are at 2° and 178°, as shown in Fig. 184a. This may be due either to direct reception on the coils of the receiving apparatus or to true vertical, both of which have been seen to give this effect. The methods to adopt for eliminating vertical component and direct reception are summarised on page 34.



(a) (b) (c)

Fig. 184. (*a*) *Two Degrees of "Vertical."*
(*b*) *Twenty Degrees of Rotation.*
(*c*) *Combination o*, (*a*) *and* (*b*).

The second type of error is illustrated in Fig. 184b, where the minima are opposite to one another, but rotated through an angle of 20°. This shows that the pointer has moved on its spindle, and if the same amount of displacement is noticed when checking the other aerial the fault may easily be rectified by an adjustment of the pointer.

[If the aerials are not erected North-South and East-West a rotation of the pointer will, of course, be necessary in any case in order that the 0° point on the scale should register a bearing true North. (See pages 205 and 256)].

A combination of the two errors is shown in Fig. 184*c*.

Mutual. The symptom of mutual inductance or capacity between the aerials has been seen on page 55 to be an indefinite minimum, which may possibly be displaced, and the following test should always be made as soon as the receiving apparatus is installed to ensure that the aerial system is not at fault.

Some kind of exciting coil, such as a high-note buzzer and dry cell connected across the coil of a wavemeter, must be placed under one of the aerials (A). A position near the aerial anchor will probably be found suitable, depending upon the

degree of amplification used in the receiver. The whole of the apparatus is then tuned up to buzzer wavelength.

Now disconnect aerial (A) and adjust the position of the exciter coil until no signals are heard in the telephones, indicating that the exciter coil and the other aerial (B) are not coupled.

Leaving the exciter circuit in the same position, disconnect aerial (B) and connect aerial (A), and again obtain silence in the telephones; this time by adjusting the position of the search coil, indicating that aerial (A) and the search coil are not coupled.

Now connect both aerials, and if buzzer signals are heard there is mutual induction or else capacity coupling between the frames or some part of the aerial circuit. The reason for this is as follows. Since the search coil is in a position in which it is unable to receive any signals from aerial (A), any buzzer signals must be received via the aerial (B). This aerial, however, is not coupled with the buzzer coil, so that it follows that the signals must be received on aerial (A), communicated to aerial (B) by means of the coupling between the frames, and thence to the search coil.

If the coupling happens to be only slight, it can probably be corrected by altering slightly the relative positions of the leads from the leading-in insulator to the D.F., so as to introduce an equal and opposite inductive coupling. If it is found that this balance is not maintained on changing the wavelength, it may mean that the coupling was a capacity one and a balance of the latter type must be arranged, although this type is seldom met with in practice.

Should the signals from the buzzer be very loud when the two aerials are connected, the trouble is more likely due to errors in the laying out of the aerials and their directions should be checked to make sure that the two frames are exactly at right angles.

To show the sensitiveness of the test, it may be mentioned that when using high magnification and tuned aerials the effects of the coupling of taut aerials, due to their swaying in a light breeze, can be easily detected, and for this reason the lower members of the aerials are sometimes cross-stayed.

Direction Finding. With the M-B-T apparatus, bearings are always taken on minimum signals and are read off in terms of degrees East of North.

When the whole circuit is tuned to the wavelength of the signal, the direction of which it is required to find, the pointer of the D.F. is moved to a position on the scale near that at which the signals vanish or reach a minimum value. In many cases a perfectly crisp and well-defined vanishing point can be found, but it is not advisable to take this as the bearing. In the majority of cases it will be correct, but in practice the freak bearings due to night effect are sometimes found to be less pronounced if a " swing " bearing be taken, and when using the aperiodic aerial system, the " coupling error " is to a large extent eliminated by this means.

Swing Readings. This method consists in matching the intensity of the sound on either side of the point of minimum signal strength, and owing to the sensitiveness of the human ear it is a singularly accurate method. In the case of very weak signals, there is no alternative to this procedure, since there may be an arc of several degrees on the scale over which the signals are not heard at all, or at any rate the minimum is very ill defined, or what has been termed " woolly."

The swing may extend over about 40°, that is, 20° on either side of the minimum, and after some practice this can be done with great speed and accuracy. The mean of the two scale readings, where the two signal strengths are exactly equal, is the position of the true minimum. Where time permits, both minima of the figure eight reception diagram should be inspected to ensure that no vertical is present, and if the two minima are fairly sharp but not exactly opposite to each other, then the mean of the two minima may be taken as the true maximum, the required bearing being 90° from this maximum. A glance at Fig. 18 or 184*a* will prove this to be correct.

Another method of taking readings about the minimum point by means of matching sounds of equal intensity is to adopt two search coils, which are fixed relatively to one another at an angle of, say, about 40°. If, now, a switching key be arranged so that alternately one and then the other search coil is put in circuit, a position can be found at which the two sounds are equal and the reading of the bearing obtained without the necessity of swinging the pointer (19). This would appear to be an improvement on the single search coil method, but in practice the disadvantages are found to be considerably greater than the merits. One reason for this is that it sometimes happens that interference is obtained on

one search coil, whilst the other one lies in a direction of no interference, making it difficult to judge the sounds accurately. In such a case, with the single search coil, a greater or smaller swing would frequently overcome the difficulty.

APERIODIC AERIAL CIRCUIT.

Fig. 185 shows the lay-out of the apparatus of the aperiodic circuit, and the chief differences between the installation of this and the tuned circuit are as follows :—

(1) There is less trouble due to coupling between the aerials, owing to the fact that the two loops are not oscillatory at the minimum point of signals (page 58) and hence a comparatively tight coupling is required between them in order to influence the minimum appreciably.

(2) Additional precautions are necessary for screening the apparatus from direct reception owing to the fact that signals are weaker with untuned aerials, and the high amplification which is thereby necessitated results in the direct reception of the coils of the transformer and the radiogoniometer being emphasised.

(3) Vertical is also more pronounced for the above reason.

To continue the comparison between this and the tuned aerial circuit, we see that the aerial tuning buzzer and wavemeter are omitted. Since there is no aerial balancing to be done in the aperiodic system, the special form of wavemeter and buzzer is not necessary, and when it is required to calibrate the set for wavelength it may be done by means of any form of wavemeter which can be excited by means of a cell and buzzer as in the case of the ordinary wireless receiving circuit.

Two double pole two-way switches are usually arranged to perform the double function of aerial disconnecting and aerial earthing. The lightning arrester is no longer required, since the aerials are permanently earthed via the mid points of the field coils, and hence the trouble due to discharges from charged clouds is to some extent removed. The earthing switches, however, serve as a further protection to the apparatus when not in use.

Although the aerials have not to be disconnected for balancing, it is still necessary to be able to receive on either separately, to ascertain that the minima are in the correct

position on the scale, and it is also more easy to detect the presence of vertical when only one aerial is connected, because in this case there are two definite positions for the minima and any discrepancy must be due either to vertical or direct.

Whilst it is still very necessary to keep the resistance of each loop the same, and also as low as possible, the leads from the aerial disconnecting switches to the radiogoniometer need not be supported with the same care that is exercised in the case of tuned aerials. There is very little chance of introducing serious errors, even if the aerial leads be made of flexible insulated cable and are allowed to lie on the receiving table. It is also found that an appreciable amount of mutual inductance between the aerial systems has a very much smaller effect upon the aperiodic aerials than in the case of the tuned ones.

Earthing of Receiving Apparatus. In Fig. 185 there are seen to be three earthing leads to various parts of the circuit. E_1 is the common connection of the two aerial earthing switches, E_2 the mid point of the field coils, and E_3 the transformer shield and " B " terminal of the amplifier (as shown); or, alternatively, the common negative of the batteries—whichever is found to give the better minima.

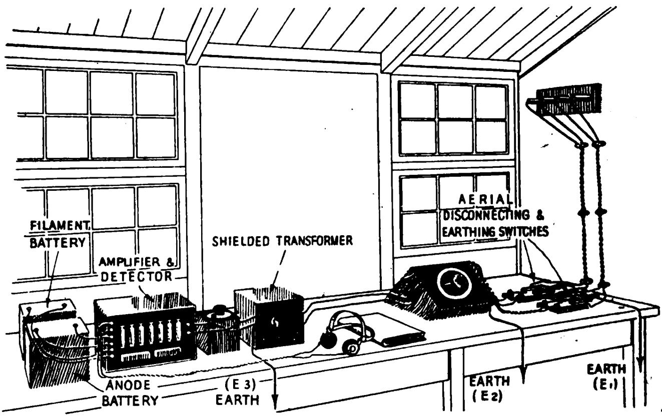


Fig. 185. *Lay-out of Aperiodic Aerial Circuit.*

Tuning. The adjustment of the circuit to a desired wavelength consists only in varying the single condenser in the receiver circuit until the whole system is in tune, as evinced by the maximum strength of signals from either a

tuning buzzer or the distant station. There is, of course, no balancing to be done.

Checking for Vertical, Direct and Mutual. The same procedure should be carried out as for tuned aerials (page 237).

Direction Finding. This is identical with the method described for tuned aerials (page 239).

Sharpness of Minima with Aperiodic Aerial Circuit. In the simple aperiodic aerial circuit a considerable amount of additional damping is introduced by the use of the shielded transformer, and owing to the tight coupling of the radiogoniometer, this damping is transferred to the aerial circuit, together with losses in the radiogoniometer itself. Owing also to the consequent reduction in signal strength, more amplification is generally used, and, unless great precautions are taken, there is appreciably more direct reception on the coils of the apparatus. These factors produce blunt and indefinite minima. By taking extreme care with the screening of all parts of the circuit it has been demonstrated that the crispness of the minima and the sensitiveness of the aperiodic aerial circuit may be made quite equal to that of the tuned aerial circuit.

APERIODIC AERIAL, LOOSE-COUPLED INTERMEDIATE CIRCUIT, HEART-SHAPE RECEIVER.

In Fig. 43 the theoretical diagram of the above circuit was shown as adapted for the determination of sense, and it was seen that the heart-shape diagram of reception could be obtained without the aid of a special vertical aerial, the natural "vertical" effect of the loop aerials being capable of supplying an E.M.F. which was leading 90° on the loop E.M.F. and the amplitude of which was more than sufficiently great to give a true heart-shape. A resistance in series with the vertical aerial lead was also seen to perform the double function of stabilising the phasing of the circuit, and also adjusting the amplitude of the current in the vertical aerial.

Aside from the use of the heart-shaped polar diagram of reception for the determination of sense, there are three other ways in which this type of circuit is superior to the figure eight diagram, which are as follows :—

(1) X stopping, when atmospherics are directional.

(2) Duplex reception, *i.e.*, elimination of interference from local transmitting station.

(3) Direction finding during, or detecting the presence of "night effect."

When used for any of these purposes it is important to obtain a complete zero of signals at the minimum point of the polar diagram, and some instructions on how to operate the circuit are given below.

The aerial system, the lead-in of the aerials and earthing switches are exactly the same as in the case of the aperiodic aerial lay-out just described, and the same precautions must be taken against mutual inductance, and great care to avoid direct reception by the receiving apparatus. When the circuit is in use for any of the three above-mentioned purposes there will be less need for constant adjustments of the radiogoniometer, and the whole of the apparatus may with advantage be enclosed in a screening case, although the necessity for this may be avoided by very careful screening of the individual pieces of the apparatus, as in the case of the set shown in Fig. 190.

The arrangement of the circuit is shown in Fig. 186 and corresponds to the diagram of Fig. 189.

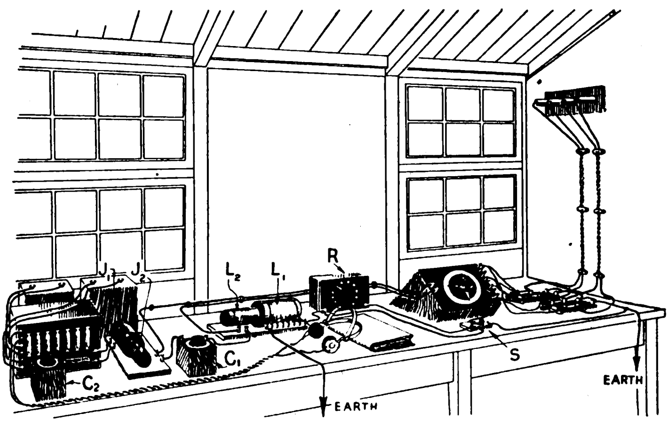


Fig. 186. *Lay-out of Aperiodic Heart-shaped Diagram Circuit.*

The radiogoniometer used is of practically the same electrical design as that shown in Fig. 177, but is fitted with an additional pointer for indicating the sense after the direction has been found by figure eight reception. (See page 67.)

The remaining apparatus consists of a variable resistance R, which should be non-inductive, two inductances L_1 and L_2 with variable coupling, a similar pair of inductances J_1 and J_2, and variable condensers C_1 and C_2.

The Intermediate Circuit. The intermediate circuit is seen to consist of the inductance L_2, the condenser C_1, the jigger primary J_2 and the search coil. The jigger secondary J_1 has a suitable tuning condenser C_2 in parallel with it, and is connected to the A and B terminals of the amplifier.

The "Vertical" Aerial Circuit. Actually, as already explained, it is usual to dispense with the separate vertical wire and to use the bunched aerials, making connection to the mid point of the field coils of the radiogoniometer. Between this mid point and earth, the circuit includes the variable resistance R and the inductance L_1, which has a number of tappings in order that the correct value of inductance shall be obtained to tune the vertical aerial circuit a little short of the received wavelength, a necessary condition for resistance phasing. The values of the phasing resistance R and the coupling between the coils L_1 and L_2 will, of course, depend very largely on the range of wavelength of the circuit; but some figures are given on page 249 in connection with another similar circuit which will serve as a guide.

Adjustment. In adjusting the apparatus, first disconnect the vertical aerial circuit and tune the intermediate circuit so as to get a satisfactory figure eight reception with sharp minima and the least possible amount of "vertical" and "direct." The latter is fatal to the attainment of a crisp heart-shape minimum, and in the case of duplex working, when a high-power transmitting station may be within a few miles, the problem of eliminating direct reception is sometimes a difficult one. Now connect up and make preliminary tuning of the vertical aerial circuit R L_1, having rotated the search coil to a position of figure eight minimum. Adjust the coupling of L_1 L_2 to some moderate value, and having obtained maximum signals by varying L_1 (indicating approximate resonance in this circuit), the inductance L_1 should be reduced slightly from resonance value. (See page 66.)

It is unlikely that the correct adjustment of the whole circuit will be obtained at the first trial, and on rotating the search coil the polar curve of signal strength will probably take the form of either that shown in Fig. 187 or in Fig. 188. The former shows the effect of too great an E.M.F. in the intermediate circuit, due to the vertical aerial, and the latter the reverse condition, and it must be remembered that this E.M.F. may be varied either by the resistance R or the coupling L_1 L_2. The resistance R, however, is also in use for

varying the phase condition of the vertical aerial circuit and will have a definite best value depending on the amount which this circuit was detuned by the slight reduction of the inductance L_1. The ensuing balancing operation to obtain the single crisp minimum will therefore be a compromise between the values of R and the coupling L_1 L_2. Having obtained one or the other of the polar curves, first vary the coupling until the best minimum is obtained, and then vary R slightly. If the minimum is still indefinite, the phasing of the vertical aerial is probably incorrect, and L_1 should be slightly altered and the balancing process repeated until a complete zero of signals is obtained.

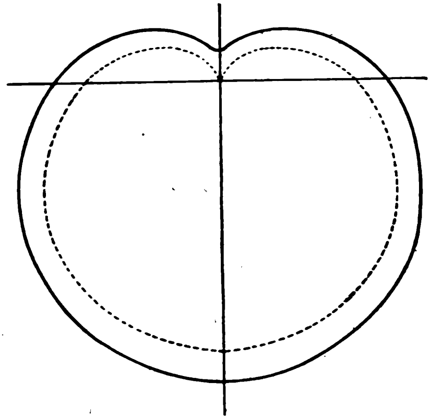


Fig. 187. *Distortion of Heart-shaped Diagram due to Too Great an E.M.F. induced by Vertical Aerial.*

Factors producing Indefinite Minimum with Heart-shape Reception. The principal factors which prevent the attainment of a complete zero of signal strength at the minimum are as follows :—

(*a*) Unequal amplitudes of E.M.F.s due to vertical and loop aerials.

(*b*) Incorrect phasing of the vertical aerial.

(*c*) Direct reception by the radiogoniometer, intermediate circuit, jigger or amplifier.

(*d*) Out-of-balance capacity of frame aerials to earth.

(*e*) Insufficient damping in the vertical aerial circuit.

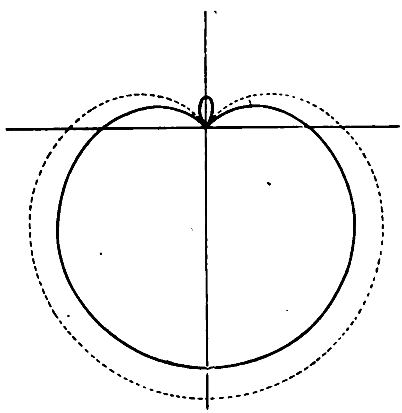


Fig. 188. *Distortion of Heart-shaped Diagram due to Too Great an E.M.F. induced by Loop Aerials.*

When it is found possible to get a true heart-shape balance of continuous wave signals, but not on atmospherics or spark signals, the last-mentioned factor above may frequently be the cause. The loop aerial is, of course, completely aperiodic at the point of minimum signals, and it is necessary that there shall be enough resistance in the vertical aerial to render this practically aperiodic if it is desired to obtain a balance on damped signals.

D.F.—Sense—Stand-by. When using the above-mentioned circuit, some form of simple switching device should be incorporated in order that the polar diagram of reception may be rapidly changed from the figure eight to the heart-shape, and provision may also be made for non-directional reception for the purpose of standing by for signals. In Fig. 189 a simple switching arrangement has been illustrated which enables the three operations to be effected, namely, D.F., sense and stand-by, and a similar scheme is shown in the lay-out of the circuit. (Fig. 186.)

D.F. With the switch in position (1) the mid point of the field coils is earthed, and the result is the simple aperiodic aerial system with a loose-coupled receiver, for it will be seen that the phasing resistance R and the vertical aerial coil L_1 are out of circuit.

Sense. With the switch in position (2) the mid point of the field coils is connected to earth through the phasing resistance R and the coil L_1, which gives the condition for heart-shape reception.

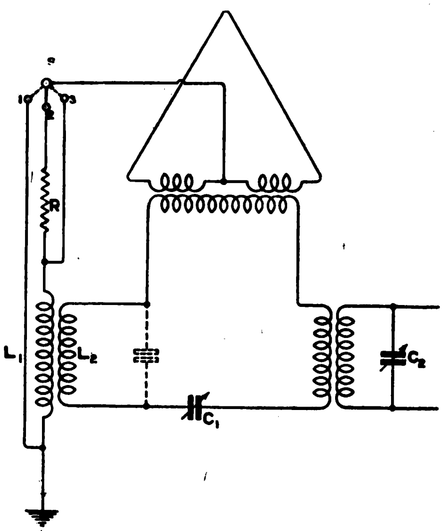


Fig. 189. *Switching Circuit for* (1) "*D.F.*" (2) "*Sense*" *and* (3) "*Stand By.*"

Stand-by. With the switch in position (3) the circuit is seen to be the same as for sense, except that the phasing resistance is out of circuit and, as a result, the current in L_1 increases several fold, with consequent increase in induced E.M.F. in L_2 and the intermediate circuit. This swamps the

effect of the loop reception and gives equal strength of signals from all directions.

In accurate D.F. work, as distinct from directional reception, the switching arrangements are more complicated, because provision must be made, when using the figure eight reception, for the coil L_1 to be totally disconnected. If this coil be connected to earth at one end, then, owing to the comparatively tight coupling between L_1 and L_2 there will be capacity coupling to earth from one side of the search coil with consequent production of vertical. (See Fig. 191.)

A SHORE SERVICE DIRECTION FINDING INSTALLATION (MARCONI).

The installation shown in Fig. 190 operates on a circuit which is a modification of the one just referred to in Fig. 189 and combines the figure eight, heart-shape and circle diagrams of reception. The range of wavelength of the set illustrated is 300 to 4,500 metres, and this entails switching arrangements which give a complicated appearance to the circuit, which is shown in Fig. 191, although actually the operating circuit on any one range of wavelength is only a very slight modification from the simple circuit of Fig. 189. Particulars of the various components, each of which fits into a separate copper screened partition in the case, are as follows :—

Radiogoniometer (Fig. 192). The general construction is clear from the illustration. Between the two ebonite end plates is a cylindrical ebonite shell, which is thick enough to give a rigid support for the field coils and allows of them being wound with a fair tension. Mounted inside this shell is the cylindrical former of the search coil, the windings of which are brought out to slip rings with gold wire collectors.

Intermediate Circuit Tuning Condenser (Fig. 193). This is the condenser C_1 of Fig. 189, and may be put in series with the search coil, the sense transformer secondary L_2 and jigger primary P for long waves, or by means of the switch on the transformer panel, the condenser may be placed in parallel with the sense transformer secondary for short waves.

Transformer Panel (Fig. 194). The shielded transformers and phasing resistances are mounted on this panel, and the switching system enables any one set to be put into circuit, the other two being sufficiently well isolated to prevent any detrimental effect. There are three transformers and three resistances, the limits of wavelength and other electrical

constants being given below. The resistances are designed to give correct phasing at the centre of each wavelength range,

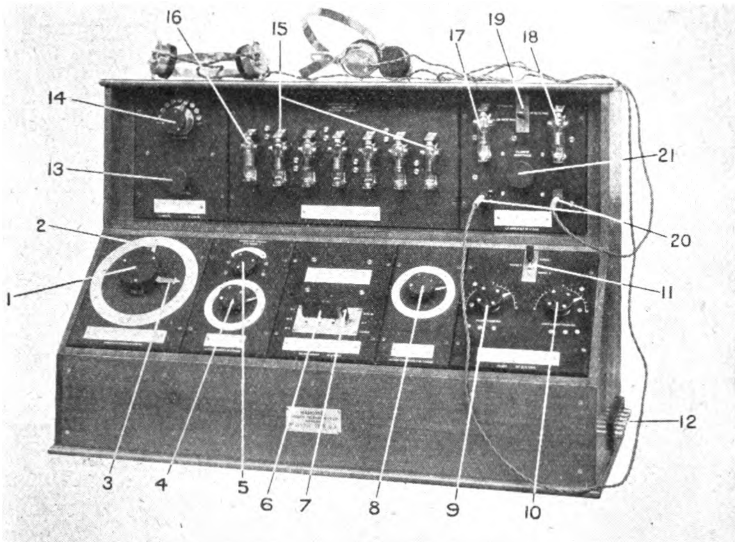


Fig. 190. *M.-B.-T. Shore Pattern D.F. Receiver (Marconi).* (1) *Radiogoniometer.* (2) *Pointer for use on Cosine Diagram of Reception.* (3) *Pointer for Sense Determination.* (4) *Intermediate Circuit Condenser.* (5) *Intermediate Circuit Condenser Range Switch.* (6) *Transformer Range Switch.* (7) "*D.F.*," "*Sense*," "*Stand By*" *Switch.* (8) *Jigger Condenser.* (9) *Jigger Coupling.* (10) *Heterodyne Coupling.* (11) *Jigger Range Switch.* (12) *Terminal Block.* (13) *Potentiometer for H.F. Amplifier.* (14) *Valve Filament Rheostat for H.F. Amplifier.* (15) *H.F. Amplifying Valves.* (16) *Rectifying Valve.* (17) *First Stage Note Magnifying Valve.* (18) *Second Stage Note Magnifying Valve.* (19) *Note Magnification Switch.* (20) *Telephone Plug Connections.* (21) *Filament Rheostat for Note Magnifying Valves.* (*Refer also Figs.* 191 *to* 199.)

and at either limit of the range there is still a great enough difference between minimum and maximum signal strength on the heart-shape to prevent any possibility of ambiguity when examining the two figure eight minima :—

	Range 1.	Range 2.	Range 3.
Transformer primary ..	174 mhy.	178 mhy.	178 mhy.
Transformer secondary ..	320 mhy.	510 mhy.	2,950 mhy.
Mutual inductance ..	126 mhy.	126 mhy.	170 mhy.
Phasing resistance ..	2,746 ohms	3,040 ohms	4,760 ohms
Minimum wavelength ..	300 m.	750 m.	1,800 m.
Maximum wavelength ..	750 m.	1,800 m.	4,500 m.

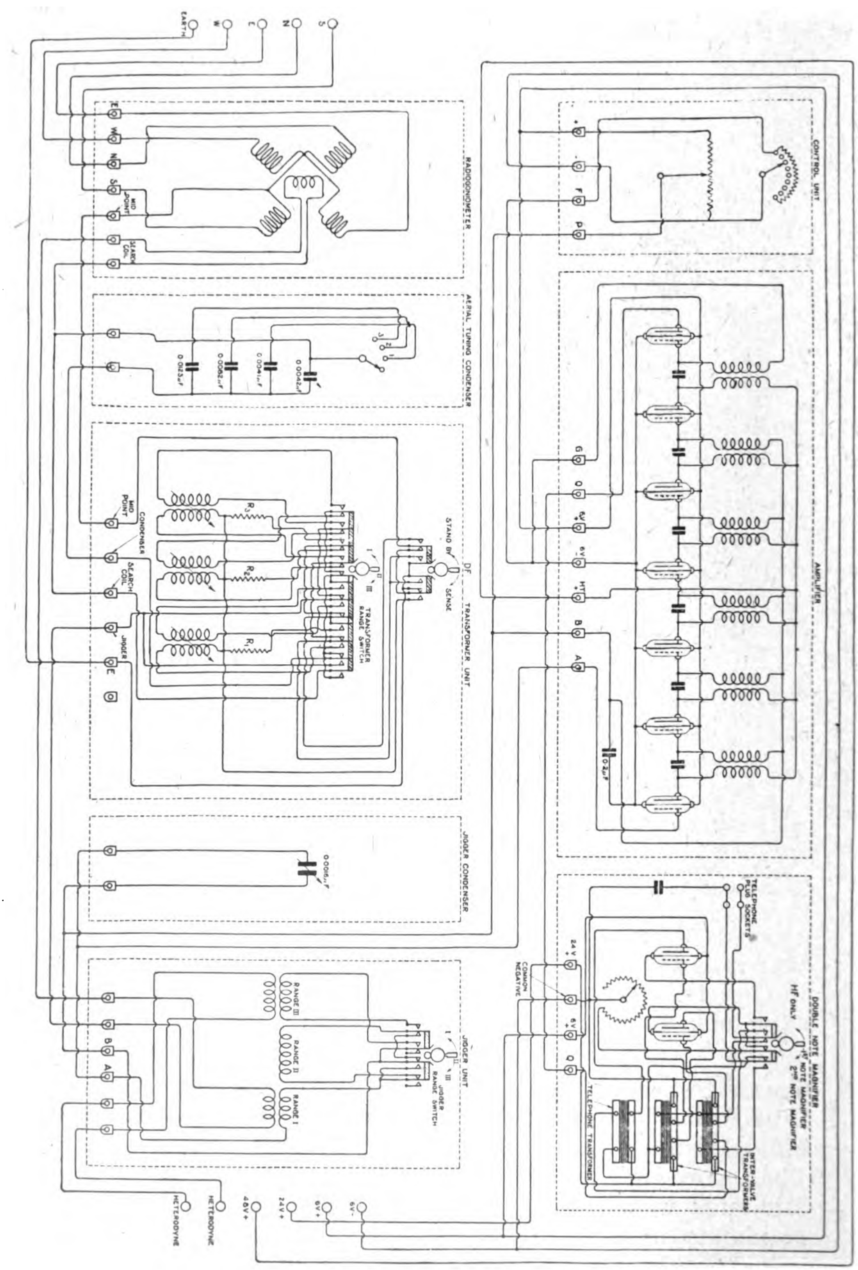


Fig. 191. *Circuit of D.F. Receiver Shown in Fig.* 190

Telephone pattern switch keys are used throughout, and in the front view of the transformer panel (Fig. 190) it will be seen that the condenser switch and the two switches for the transformer primary and secondary are all linked by a cross-bar, which is thrown to the Up, Centre, or Down position for the short, medium, or long wavelength ranges respectively.

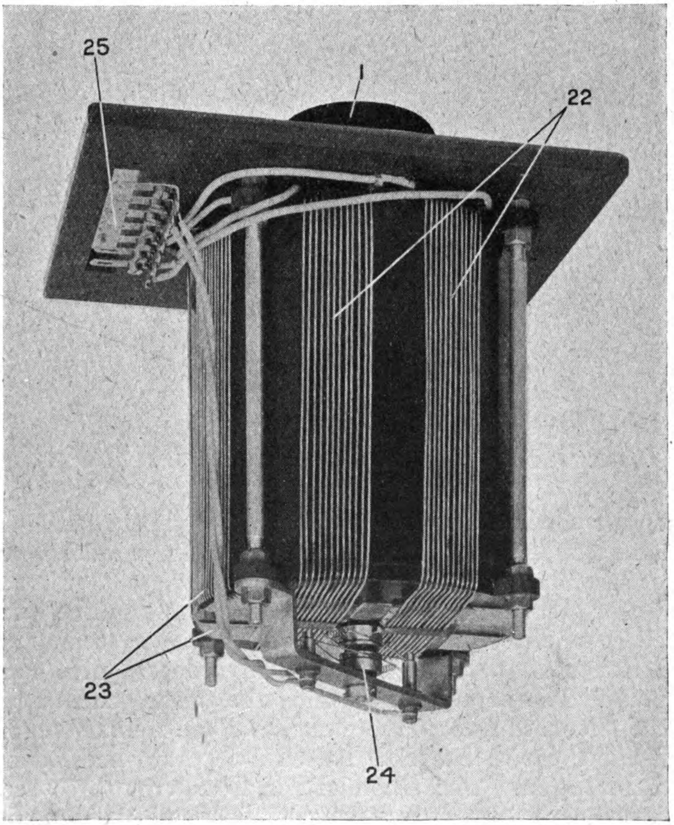


Fig. 192. *Radiogoniometer.* (*See Fig.* 190.) (22) *and* (23) *Split Field Coil Windings.* (24) *Search Coil Slip Rings.* (25) *Connections to Internal Wiring of Case.*

To the right of this linked triple switch is the D.F.—Sense—Stand-by switch, the function of which has already been stated. In order to discourage bearings being taken on the heart-shape minimum the switch is arranged to be non-locking in the sense direction, and must be held over during the

moment or two necessary to ascertain the sense. The centre, or normal position, is that of D.F., and the switch locks when thrown to stand-by.

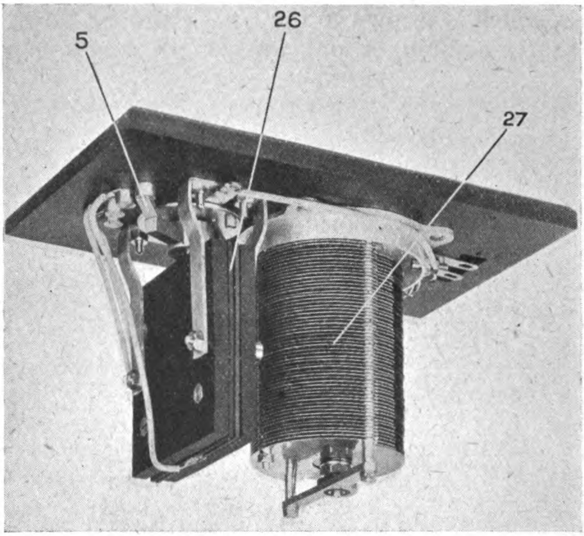


Fig. 193. *Intermediate Circuit Tuning Condenser.* (*See Fig.* 190.) (26) *Block Condensers in Parallel with Variable Condenser* (27).

Jigger Condenser (Fig. 195). This panel contains the variable condenser, which is connected in parallel with the jigger secondary and the amplifier.

Jigger (Fig. 196). The jigger primary is wound on a former which is mounted inside the cylindrical jigger secondary coil in a manner capable of rotation, in order to give variable coupling. The handle for rotating the jigger primary is seen on the left-hand side of the panel, and the similar one on the right-hand side, is associated with a separate heterodyne for C.W. reception. The secondary is wound in three sections for the three ranges of wavelength, the switch being arranged to isolate the sections not in use.

Control Panel and High-frequency Amplifier. The amplifier (Fig. 198) is equipped with six magnifying valves and a rectifier, the filament current controlling resistance being mounted on a separate panel (Fig. 197). The intervalve transformers have a 1 : 1 ratio of winding, the resistance of both primary and secondary being about 25,000 ohms for the

wavelength range of 300 to 4,500 metres. The small intervalve condensers have a capacity of about 0,001 microfarads. The steady potential on the grids of the magnifying valves is obtained by means of a potentiometer, which is connected across the filament-heating battery and which is mounted on the separate control panel. The potentiometer is shunted by a 0.2 mfd. condenser.

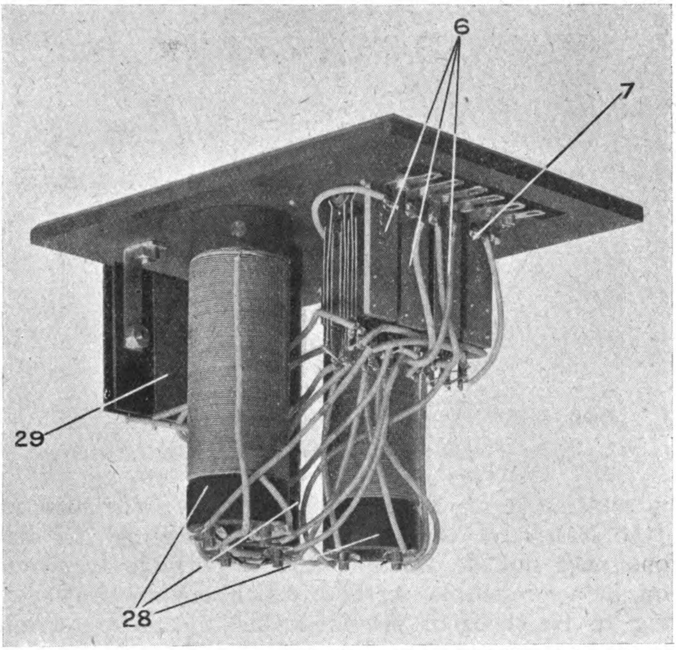


Fig. 194. *Transformer Panel.* (*See Fig.* 190.) (28) *Three Transformers.* (29) *Three Phasing Resistances.*

Note or Audio-frequency Magnifier (Fig. 199). This is a two-stage amplifier with a switch whereby the degree of amplification can be varied or the telephone transformer may be connected direct to the rectifying valve of the H.F. amplifier. The intervalve and telephone transformers have closed iron cores, the plate and grid windings of the former being 4,500 and 1,500 ohms respectively and the low resistance telephone windings 12 ohms. Provision is made for two pairs of low-resistance telephones, which are connected in parallel. The filament current is cut off by the same switch which controls the magnification.

CALIBRATION.

When the station has been erected and the apparatus installed and tested, the next and final process is the calibration or checking of the observed bearings at a number of points on the scale.

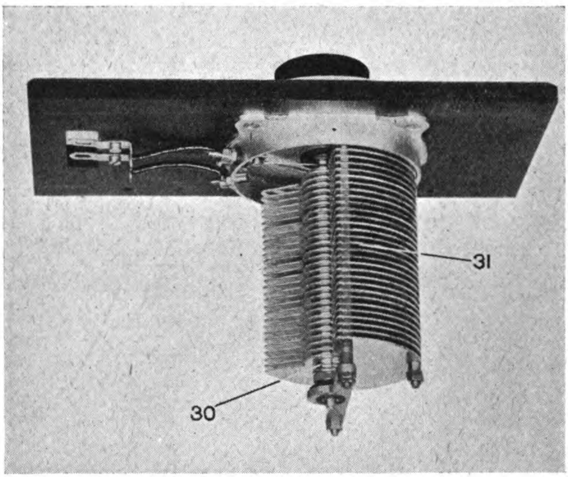


Fig. 195. *Jigger Condenser.* (*See Fig.* 190.) (30) *Slip Rings.* (31) *Fixed Vanes of Variable Condenser.*

The rotating frame D.F. will usually have a smaller range than the M-B-T, so that calibration by bearings on distant stations may not be feasible, and a portable transmitting station is a preferable method which enables any desired bearing to be checked, provided that means are available for finding the exact position of the mobile station at the instant of transmitting. A method which is used in the case of some of the American coastal D.F. stations is to take bearings on a ship which cruises along the coast at the maximum visible range and simultaneous wireless and optical bearings are taken, using for the latter purpose a sextant, theodolite or similar instrument. It is necessary to ascertain the direction of true North in the first place, and once this is done the true and observed bearings may be written down and an error chart prepared for future reference.

In making use of a ship for this purpose which has an aerial of the inverted L type, it is advisable that the range should, if possible, be not less than about five miles, as bearings of

transmitting stations using this type of aerial are found to be unreliable at short ranges. A way of overcoming the difficulty is to take two sets of readings, one with the ship travelling in one direction up the coast and the other when she is going in the reverse direction, in which case the mean of the two sets of bearings will give a close approximation to the correct values (77).

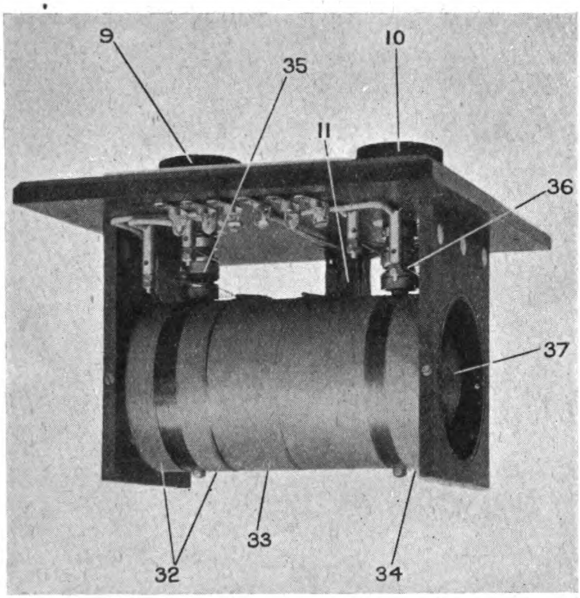


Fig. 196. *Jigger Panel.* (*See Fig.* 190.) (32), (33) and (34) *Ranges* 3, 2 *and* 1 *of Jigger.* (35) *Jigger Coupling Slip Rings.* (36) *Heterodyne Coupling Slip Rings.* (37) *Heterodyne Coupling Coil.*

For an inland station the problem is more difficult, and methods of locating the transmitting station must be left to the ingenuity of the persons directing the trials.

When possible, the transmitting station should use the wavelength on which the D.F. station will subsequently take bearings, as many freak effects are influenced greatly by change of wavelength.

Since the range of a M-B-T station may easily be several hundred miles for low power transmitting stations, and a thousand or considerably more than this for high-power ones, the calibration may often be performed entirely by means of bearings taken on distant stations, the true bearings

of which are either calculated or found from a gnomonic chart. This method of calibrating should only be carried out in daylight, as the presence or possibility of night effects renders night readings unreliable.

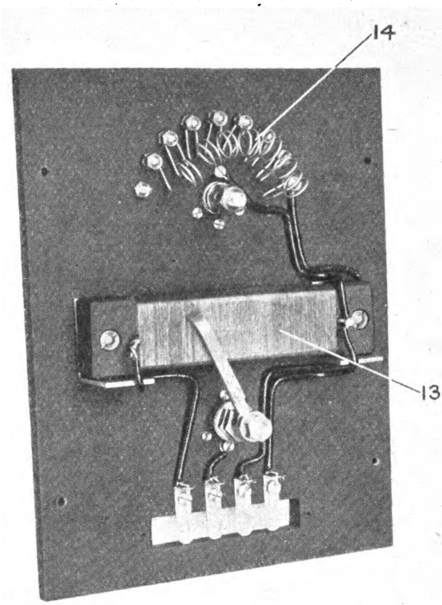


Fig. 197. *H.F. Amplifier Control Panel.* (*See Fig.* 190).

It has been seen on page 205 how the erection of the M-B-T aerial system in directions other than N-S and E-W, or the movement of the pointer of the radiogoniometer, will give a constant error all round the scale, and if this type of error is found on any type of D.F. installation, the remedy is very simple, and consists simply in a rotation of the pointer of the instrument until it reads true bearings. If the site for the station has been carefully chosen and due care taken in its erection, serious errors need not be expected, but cases arise in which it is necessary to place D.F. stations on altogether unsatisfactory sites. When a large permanent D.F. station is to be built it is advisable to erect a temporary station on the proposed site, or alternative sites, and make a provisional calibration.

In every case the first thing to do, having obtained a list of observed and corresponding true bearings, is to tabulate the results, find the errors, and plot an "error curve." This curve should have a horizontal base line representing scale readings in degrees from 0° to 360°, and the vertical ordinates are errors reckoned positive above the base line and negative below it. It is very important that the errors be plotted against the corresponding *true* bearing, and not the observed bearing, otherwise the curve will be displaced laterally at each point by the amount of the error at the point, and thus distorted from its true shape.

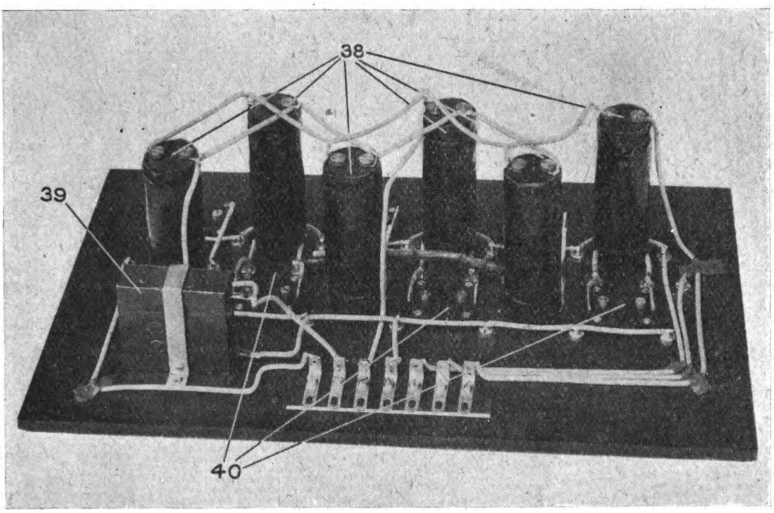


Fig. 198. *H.F. Amplifier.* (*See Fig.* 190). (38) *Intervalve Transformers* (39) *Condenser Shunting Potentiometer on Control Panel.* (40) *Intervalve Condensers.*

In rotating frame D.F. stations it is usual not to attempt to make adjustments for the purpose of neutralising the errors which are found, but an error chart is made out for the use of the telegraphists and the observed bearings are corrected before being used.

A set of readings are tabulated overleaf which were obtained from a station in which a considerable quadrantal error was present. in addition to small errors due to local screening, etc.

Observed Bearing.	True Bearing.	Error.
25°	21°	+4°
$33\frac{1}{2}$°	33°	+ $\frac{1}{2}$°
43°	45°	−2°
58°	63°	−5°
88°	92°	−4°
119°	120°	−1°
$155\frac{1}{2}$°	153°	+$2\frac{1}{2}$°
187°	181°	+6°
197°	195°	+2°
223°	225°	−2°
281°	285°	−4°
333°	328°	+5°

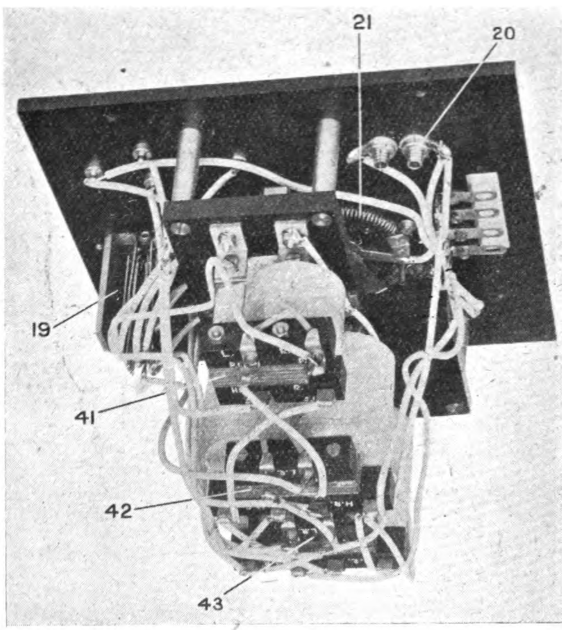


Fig. 199. *Double Note Magnifier.* (*See Fig.* 190.) (41) *Telephone Transformer.* (42) *and* (43) *Intervalve Transformers.*

Quadrantal Error. On plotting the errors from the above table it is found that they lie roughly in the shape of a double sine curve (Fig. 200), the maximum positive error being at 170° and 350° and the maximum negative errors are 80° and 260°, whilst the curve crosses the base line and hence

indicates positions of no error at 35°, 125°, 215° and 305°. These effects are illustrated in Fig. 201, where the true bearings are shown by full lines, and the observed bearings by dotted lines, and it will be noticed that in the four quadrants between the four positions of no error, A, B, C and D, there is a distinct drift or bias of all observed bearings towards the direction 35° and 215°, as though the receiving power of the station were greater in this direction. In a ship installation this direction always coincides with the centre line of the hull of the ship, and in an aeroplane a similar effect is generally noticed. On shore stations the phenomenon is not so clearly marked as in a ship, and may be indefinite and not easy to distinguish among other small discrepancies.

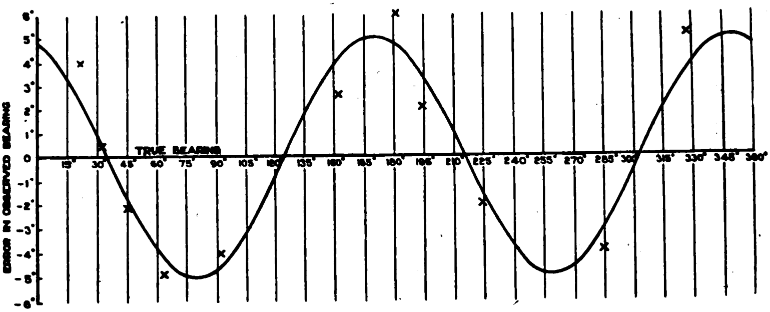


Fig. 200. *Error Curve of Uncalibrated D.F.*

Elimination of Quadrantal Error. As mentioned above, it is not usual practice to do more than make allowances for this error in a rotating frame D.F., but suggestions have been put forward for methods of reducing the error to a negligible amount and have been found to work if carefully applied. One method is to erect a small fixed frame aerial in the direction to which bearings appear to drift, and couple this aerial to the receiving circuits. The size of the frame and the degree of coupling are so adjusted that an equal and opposite E.M.F. is introduced into the receiving circuits, which neutralises the apparent tendency of the installation to greater receptive power in this direction.

A modification of the above method has also been suggested for the M-B-T system, which involves a small fixed frame as before, which is associated with a third set of field coils in the radiogoniometer; but a simpler method of making the correction exists, and we shall now consider the error curve

of Fig. 200 and the method of reducing the quadrantal error, with particular reference to the M-B-T system.

Had the direction towards which the crowding took place coincided with the direction of one of the M-B-T aerials, the aerial system itself might be suspected. Unsymmetrical loops or bad contact in one aerial circuit will give one of the aerials a greater receptive power than the other, and produce such results. In the present case, however, the direction is intermediate between the aerials, and the distortion must be attributable to some other cause. The field coils of the radiogoniometer may be at fault, but this may be easily checked by ascertaining whether the direction to which the bearings are crowded is such that when the pointer is in this position the search coil is exactly parallel to a set of field coils. Unless this is the case, the possibility of constructional error is very slight.

Theory of Method of Making Correction. If, in the M-B-T aerial system, one of the loops be made very much larger than the other, then the E.M.F. round the larger loop, and hence the current in the loop, will be proportionately greater than it would be for the normal aerial. Assuming that the field coils of the radiogoniometer remain symmetrical, then, for any given signal arriving in a direction intermediate between the planes of the two aerials, the current in the larger frame, and hence the magnetic field in the associated field coils, will be disproportionately large and the resultant field will be distorted. The polar diagram of the system as a receiver will, in fact, no longer be the simple figure of eight, or in other words, it will not follow the cosine law.

The effect of this upon the bearings taken at the station will be that they are all distorted towards the direction of the larger aerial. (In the limit, when the smaller aerial is reduced to nothing, all bearings would clearly be in the direction of the single remaining frame.)

When errors of the above type appear and can be traced to inequality of the aerials, there are two ways in which they may be eliminated. The most obvious way is to reduce the size of the larger frame, and the other is to put chokes in series with the aerial circuit in the case of the larger frame until both have the same receiving power. This latter method is more applicable to ship installations, and is dealt with again on page 292.

If the direction towards which bearings are distorted is not due to inequality of the aerials, and, moreover, does not coincide with the plane of either of the frames, then the above simple remedies cannot be applied.

Referring again to Fig. 201, it was seen that the direction in which bearings were distorted was the line 35°—215° East of North. Suppose now that the complete aerial system be rotated 35° in a clockwise direction, and the pointer of the radiogoniometer be rotated on its spindle through 35° in the *opposite* direction. If the errors were actually due to some special condition in connection with the site and were entirely independent of the aerial system itself, then we have now exactly the same error curve as before (Fig. 200), but we have also an aerial system in which the planes of the two frames lie in the directions of no error, one of which directions is always that towards which bearings are distorted.

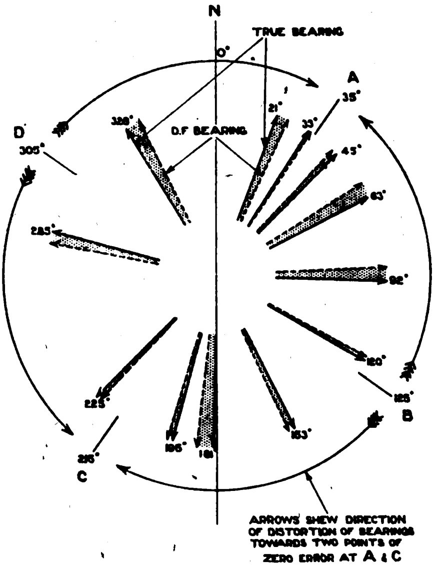


Fig. 201. *Distortion of Bearings of Uncalibrated D.F.*

The symptoms are now those of an aerial system in which one frame is larger than the other, and although in this case we know this is not so, yet the same remedy may be applied, namely, that of reducing the appropriate aerial in area. This is done by taking a few feet of wire at a time out of the aerial until bearings are found to be correct, or at any rate, the errors have been reduced to a negligible amount.

Precautions in making Aerial Adjustments for Calibration. Choke Method. The chief reason why this method is more applicable to ship installations is because it renders possible the slight alterations in the calibration of the system which are sometimes necessary on shipboard, owing to an alteration in the positions of certain steel wire stays, etc.,

on the ship, or on ships where it is necessary to lower away the D.F. aerial for working the holds, and in various other circumstances. On shore, the calibration of a station is usually fairly permanent, although it may sometimes be advisable to use the choke method, for instance, when errors vary in extent on different wavelengths.

The chokes may be inserted in the form of two inductances of equal value on either side of the field coil of the radiogoniometer, and two non-inductive resistances of the same resistance as the chokes are connected in series with the other aerial with a view to keeping the resistance of the two loops as nearly equal as possible. Fine adjustment is obtained by constructing the chokes in the form of a variometer. Alternatively, two variometers may be used, one in each aerial circuit, and so linked mechanically that as one is increased in inductance the other is reduced.

Calibration by Reducing Area of One Frame. When making trial adjustments on the size of the frame, a bight should be taken in *both* lower limbs of the frame, Fig. 202 showing alternative methods of doing this. When the correct amount has been fixed upon it is not advisable to seize off the aerial and leave it, since if the length of wire cut out of circuit is at all great and an intermittent contact develops at some future time at the point where the seizing occurs, then puzzling errors will make their appearance. The aerial wire should on no account be cut and a soldered joint made, and it is advisable to remake the lower part of the frame altogether, modifying the dimensions in accordance with the information obtained from the test.

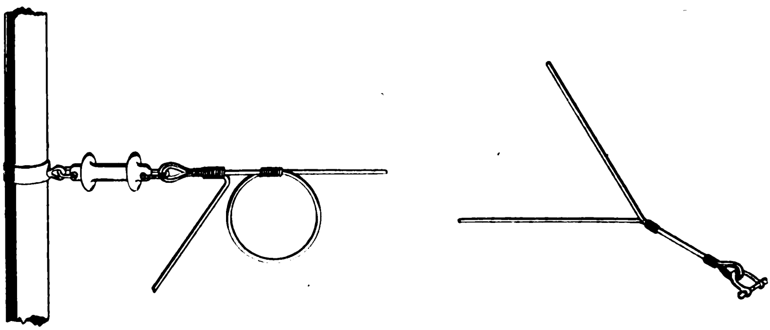


Fig. 202. *Methods of Reducing, Temporarily, Area of M-B-T. Aerial.*

Wireless and Magnetic Compass Corrections. The permanent reduction of quadrantal error in a wireless D.F. is very analogous to the corrections which are made during the compass trials of a ship. In the latter case magnets and pieces of iron are suitably arranged to counteract the magnetism of the hull of the ship, errors of as much as 45° existing before these processes are carried out.

THE MULTIPLEX SHORE D.F. STATION.

It is common practice in directional receiving stations (as distinct from direction finding stations), to connect more than one radiogoniometer to one pair of M.-B.-T. aerials, enabling a number of commercial traffic circuits to be handled by one aerial system. This is desirable in the case of long wave receiving stations on account of the large aerial employed and the consequent high cost of duplicating mast systems, etc. The bulk of shore direction finding, however, is carried out on short waves (below 1,000m.), and the necessity for multiplex stations does not arise. In any case, the problem of arranging two or more radiogoniometers to register accurate bearings on a single aerial system presents some difficulties, although polar diagrams of reception can be obtained in which the minima are sharply defined and which are hence quite satisfactory for duplex working, elimination of directional atmospherics and jamming. The further consideration of the subject may be said to lie outside the field of Direction Finding.

CHAPTER 8.

THE SHIP D.F. INSTALLATION.

The installation of accurate wireless direction-finding equipment on shipboard, and its successful operation, present a number of problems which are never met with on the shore D.F. station. Practical experience of the conditions under which the apparatus has to work at sea has resulted in a complete re-design of many essentials, including the aerial system, methods of leading-in from the aerial to the receiver, and nearly all the D.F. and receiving apparatus.

In the present chapter it is proposed to follow the lines of the previous one but to deal in detail only with the particulars in which the ship and shore M.-B.-T. installations materially differ from one another. The testing, calibration and actual direction-finding have a good deal in common.

Choice of Site for Aerials. In selecting a suitable position for the frame aerials the following important points should be borne in mind :—

(*a*) The two frames must be rigged accurately fore and aft and thwartships respectively.
(*b*) The aerials should be rigged symmetrically with regard to the centre line of the ship.
(*c*) The aerials should have the maximum possible area.
(*d*) The aerials should not interfere with or be interfered with by the rigging of the ship.
(*e*) The position selected for the aerial should be as near as possible to the position selected by the owners of the ship for the D.F. instruments.
(*f*) The aerials should, if possible, be rigged in a position which will not necessitate their being unshipped when in port.
(*g*) Each loop should be symmetrical about its central vertical axis.

The preliminary survey must usually be made whilst the ship is in port, and although under such conditions a better idea may be gained of the space required by the derricks, etc., it must be remembered that in certain cases essential steel wire stays are slacked off when working cargo. Occasions have arisen in which aerials have been rigged in apparently

ideal positions in port, and have been rendered useless later owing to a steel stay passing close to or even through the loops, producing electrical coupling between them.

Electrical interference from motors is also difficult to judge when the ship is in port, and although a site be chosen where induction from derrick motors can be eliminated, a multitude of ventilating fan motors will probably be in operation when the ship is under way or in the tropics, and may give endless trouble.

When the aerials are rigged on a boat-deck, the aerial stays must not interfere with the working of the boat derricks, and due consideration must be given to the subject of head room and the possibility of deck cargo. The aerials should always be out of reach of passengers, and should not encroach on passengers' deck space ; furthermore, no part of the installation should be placed in a position which is considered unsightly when alternatives are available.

It will therefore be seen to be advisable to have a consultation with the ship's officers before making any decisions, and, when possible, all electrical apparatus should be put in operation for the purpose of testing to what extent electrical screening of power leads, etc., will be necessary.

Chart Room or Wireless Office. The choice of location for the D.F. instruments will not, as a rule, lie with the person who carries out the installation of the gear, but the question as to whether the chart room or the wireless office is the better site is open to some doubt. In spite of several grave disadvantages, the wireless office is now the more usual site chosen, the balance of argument being in its favour for the following primary reasons :—

(1) Although an instrument of navigation, the D.F. is essentially wireless apparatus, and must be under the constant supervision of the telegraphist if he is to be responsible for its efficient working.

(2) In many ships the distance between the wireless office and the bridge may entail several minutes' walk for the telegraphist whenever a bearing has to be taken, during which time a listener must keep watch on the main receiver.

(3) By having the D.F. always available, the telegraphist may familiarise himself with its use and become expert at taking snap bearings.

(4) Although the proximity of the down lead of the main aerial is a disadvantage, the use of a moderate length of leading-in cable allows of the aerials being rigged well free of interference from this cause, without appreciably affecting the accuracy of the bearings.

(5) On some shipping lines the presence of the telegraphist on the bridge may be deemed undesirable and the conditions do not tend towards the co-operation which is so essential for the best results to be obtained with the apparatus.

(6) If the instruments are installed in the chart room, remotely controlled automatic switches are necessary to ensure, firstly, that the main aerial is insulated when the D.F. is in operation, and secondly, that the D.F. apparatus is suitably protected when transmission is taking place on the main aerial.

(7) Although the wireless office site renders it impossible, in most ships, for the telegraphist to keep in direct communication with the person taking the magnetic compass readings coinciding with the D.F. bearings, a satisfactory substitute can be found in the telephone or a prearranged system of bell signalling. If a gyro-compass be installed in the ship and a "repeater" dial in the wireless office, the conditions for accurate D.F. work are very favourable, but the gyro-compass is seldom fitted in merchant vessels.

AERIAL SYSTEMS, CHOICE OF SITE, AND METHODS OF SUPPORT.

It is rarely possible to rig aerials which even approach in size the ones used on shore D.F. stations, but loops smaller than 500 square feet in area can hardly be considered satisfactory, The proportions of the loops are important and they should, if triangular, follow as nearly as possible the shore station practice (page 214) or if rectangular, should be approximately square. Although a departure from moderate proportions may be necessary in some cases, there is always the chance that a radiogoniometer and receiving circuit which have been designed to give a correct heart-shaped diagram of reception with normal aerials, may fail to do so on extremely high and narrow loops or on very low ones.

The problem of finding a site for aerials of the requisite size becomes a serious one at times, and particularly on a small vessel such as the one shown diagrammatically in Fig. 203. Suppose that in this case, the W/T office is forward

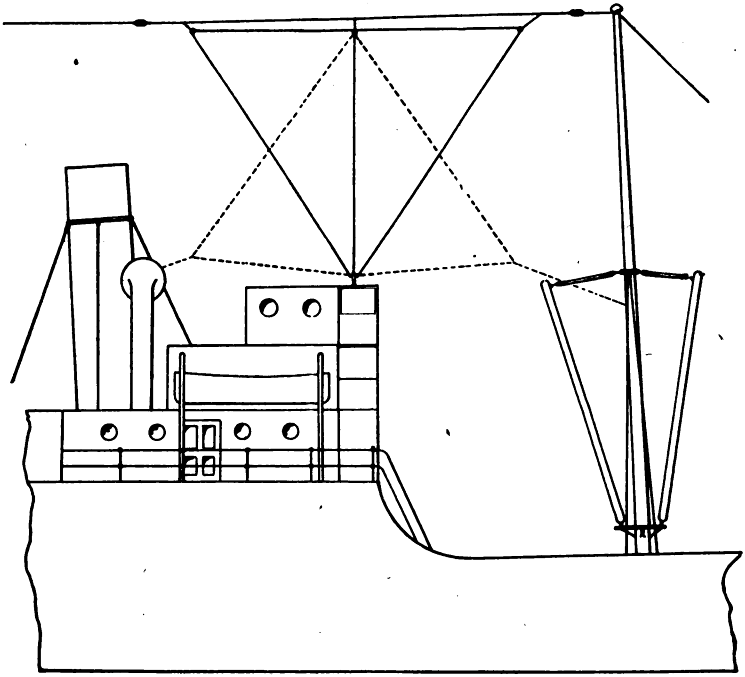


Fig. 203. *Inverted Fore and Aft Loop.*

and the only clear space for the aerials is over the bridge. The rigging of the thwartship loop is comparatively easy; a jumper stay to support the apex and the lower corners stayed out to the bridge wing shelters. If, now, the fore and aft loop be supported from the same point, as shown dotted, it will be necessary to stay out to the mast and this fore stay will foul the derricks. A method of overcoming the difficulty is to invert the fore and aft loop as shown in the figure. For this arrangement the jumper stay must be horizontal and the aerial supported a foot or so away from the stay and parallel to it, otherwise the geometrical and hence the electrical symmetry of the aerial will be destroyed.

An alternative solution is given in Fig. 204, in which the loops are separated, enabling the fore and aft loop to be

stayed out to a special spar erected over the bridge, whilst the thwartship loop remains in the same position as before. This arrangement is quite permissible, but should be avoided when either of the above symmetrical arrangements are possible. In the case illustrated the inverted loop is obviously the better arrangement owing to the considerable reduction in area in Fig. 204.

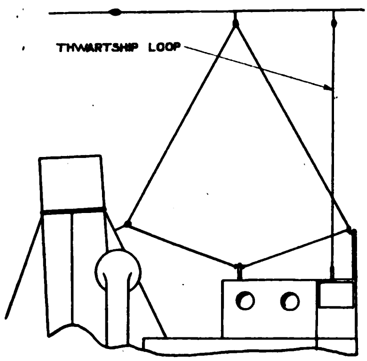


Fig. 204. *Separated Loops.*

Fig. 205 shows a not uncommon occurrence, the loops being situated so that if the lower limb of the fore and aft aerial be horizontal, one half will run immediately above a deck house, water tank, engine room casing or some similar structure, whilst the other half is free of all obstructions. In order to avoid

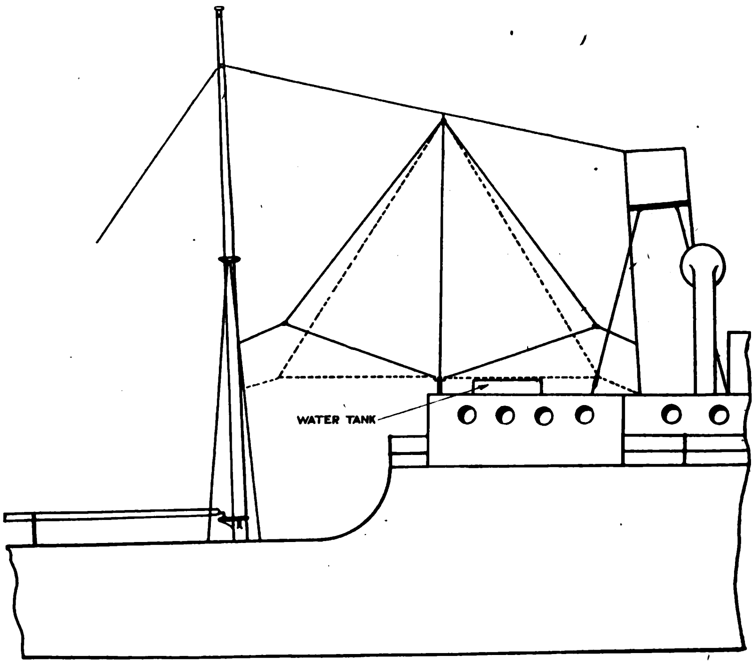


Fig. 205. *Diamond-Shaped Loop to avoid unbalance.*

certain errors which may be introduced (page 279), it is advisable to have a diamond shaped loop as shown by the full lines in the figure. The same trouble has been known to occur owing to an awning being erected under one limb of an aerial and the errors were found to be variable, depending on whether the awning was wet or dry and again the elevation of the outer ends of the loop cleared the fault.

Merchant or passenger vessels having two funnels will usually be large enough for sites to be found for the aerials which are comparatively clear positions. On the other hand, in the case of a warship, say a small cruiser, the greatest difficulty may be found in selecting an approved site. Fig. 206 shows an arrangement which has been used successfully, consisting of a square loop between the funnels and a triangular thwartship loop supported from a jumper stay between the masts. In such a case the fore and aft loop will be very much smaller than the thwartship loop, owing to the effect of the funnels, but the calibration of such a system may nevertheless be quite straightforward.

Methods of Supporting Aerials. Upper Support. There is rarely any difficulty in finding a means of support for the apexes of the aerials, as jumper stays are frequently found in convenient positions between mast and funnel or between masts. It will be necessary to insulate any such

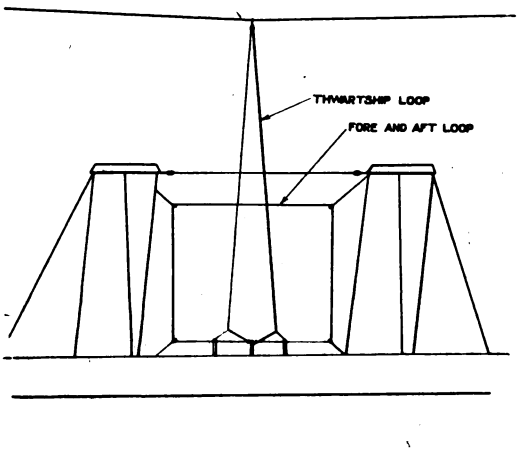


Fig. 206. *Fore and Aft Loop between Funnels.*

stay at several points along its length, to prevent losses due to induced currents, and also the extreme distortion of bearings which results when the jumper stay forms a part of a frame, as in the case when it is between funnels. Porcelain insulators of the pattern shown in the centre stay, Fig. 208, should be inserted at least every 50 feet. Failing a suitable existing jumper stay, one must be rigged, and it is an advantage to make provision, in every case, for lowering off the stay to allow of inspection and repairs to the aerial.

The stay should have a ring spliced or shackled into it at a point immediately over the position chosen for the lower support. Further details in connection with the construction of the aerial and its effective insulation are given on page 272.

Lower Support. The exact form of the lower support depends upon the form of lead-in adopted. In some cases the shore method of porcelain telegraph insulators and bare wire may be employed, but more usually some form of cable is used, and this involves a suitable support for the cable junction boxes. Fig. 207 shows a centre support designed for the normal case of aerials which have a common vertical axis, the wooden pillar being fitted with four telegraph insulators on the usual swan-neck spindles to take the strain of the lower limbs of the loops. Immediately below them are the junction boxes.

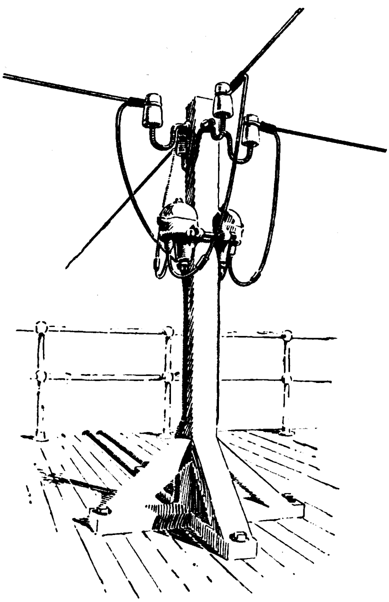


Fig. 207. Aerial Lower Centre Support showing Junction Boxes for Leading-in Cables.

The necessity for making any wooden structure of this type very robust is not only on account of the weather conditions, but also the rough treatment which it gets at the hands of persons working in the vicinity and who have not yet learned to treat the wireless compass with anything approaching the reverence displayed in the case of the magnetic compass.

Centre Support of Temporary Aerials. The temporary aerial with its rubber-covered cable lead-in should have no counterpart on a ship installation as a general rule; but cases may arise in which tests have to be made or in which a D.F. is fitted for one voyage only, and in such a case the type of aerial support shown in Fig. 208 will meet the case. It has the advantage of requiring hardly any structural alterations to the vessel beyond a deck ring and the insulation of the jumper stay.

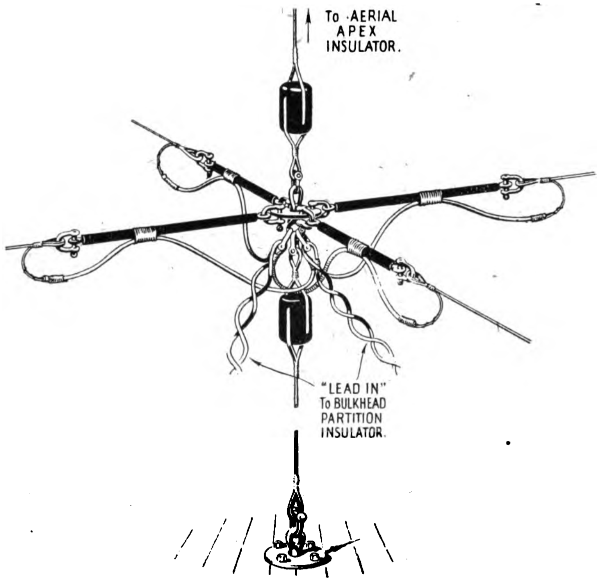


Fig. 208. *Temporary Installation; Aerial Lower Centre Support with Rubber Cable Lead-in.*

The exposure to sea air and sunlight of the rubber cable will soon destroy the covering unless it be served with protecting material, and the whole layout must be considered as only of a temporary nature.

Outer Supports. As a means of attachment for the stays from the lower extremities of the aerials, awning stanchions, bridge wing shelters, rails, etc., can be used with the permission of the authorities. In cases where convenient anchorage is not available, spars may sometimes be run out horizontally from the roofs of deck-houses, etc., which will also allow of a thwartship aerial being rigged of the required dimensions in a vessel of rather small beam.

The staying of the fore and aft loop, in the case in which the aerials are rigged over the bridge, has already been mentioned, but when the arrangement shown in Fig. 203 and 204 are neither of them possible, the final alternative nearly always remains of bringing a stay to the fore mast, and if this is liable to foul derricks it may be secured in such a way that it can easily be cast adrift when the ship is working the holds. The stay may alternatively be secured to a special spar on the lines suggested for the thwartship aerial.

Full sanction must be obtained for all structural alterations, however slight, and the standard of the work done should conform to ship practice and be as sound as possible.

The Construction and Insulation of the Aerials. The aerials are made of stranded silicon-bronze wire, about 7/19 or 7/22 in size, and the notes given on page 216 apply to the ship aerial so far as the necessity of maintaining a continuous length of wire, free from joints and kinks; but in the case of the ship aerial it is not usually possible to make the aerials to calculated dimensions as is the case with a shore station.

A method of insulating the apexes of the two aerials is shown in Fig. 209, and having decided upon the lower points of support, the aerial wire should be run through the apex insulator, through the shackles at the outer supports, the springs and insulators being in position, and then cut off to the required length at the centre support, allowing enough "tail" to reach the junction boxes, if fitted.

Having marked the positions for the thimbles at the outer corners of the aerials, and at the centre support, the jumper stay should be slacked off and the aerials measured up to make sure that they are symmetrical. That is to say, the apex insulator should be exactly half-way between the outer corners and the lower limbs should be equal. The thwartship aerial may now be permanently rigged and made off to the telegraph insulators at the centre support; but the fore and aft aerial will probably have to be altered in size during calibration, and the rigging, whilst being fairly secure, should not be of a very permanent nature. In the case of the inverted fore and aft aerial, calibration can more conveniently be effected by varying the area of the thwartship loop, which will have to be *increased* in size.

Fig. 210 shows a type of corrugated ebonite insulator used for the outer supports, and also a spring which is inserted to

allow for stretch of the aerial wire, jumper stay, etc., and also to prevent the chance of the aerial carrying away in bad weather when it is stretched taut.

A general view of the aerial system of the R.M.S.P. " Andes " is shown in Fig. 211, which is fairly typical of large passenger steamers. The photograph is taken looking aft and shows the aerials rigged over the boat deck awning support. The cable junction boxes can be seen on the centre support, and on the starboard can be detected one of the vertical spars erected to stay out the thwartship loop. The fore and aft loop has been kept clear of the awning by making it diamond shaped. The apex insulator is supported from a jumper stay, the insulators of which can be seen.

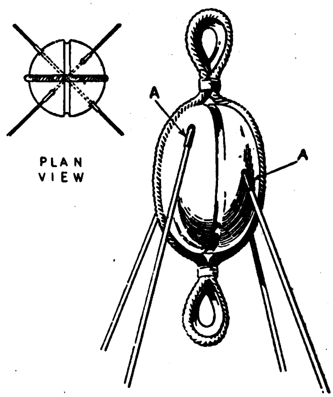


Fig. 209. *Aerial Apex Insulator.*

The aerials of the S.S. " Ballygally Head " are shown in Fig. 212, and here it will be noted that the fore and aft

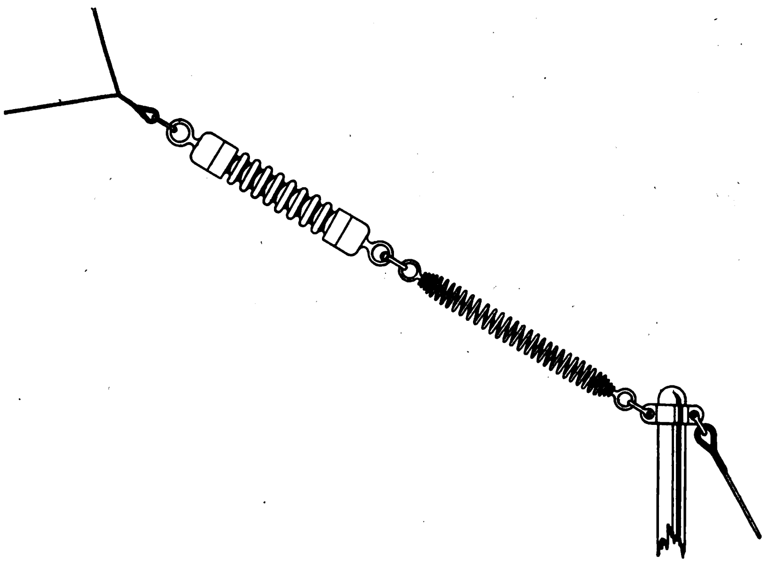


Fig. 210. *Corrugated Ebonite Insulator and Spring for Support of Outer Corners of Loops.*

aerial has been inverted to avoid staying down to the mast, with consequent interference owing to the derricks. This aerial has also been moved aft from the centre line of the thwartship loop in order to leave a clear space for the signal halyards.

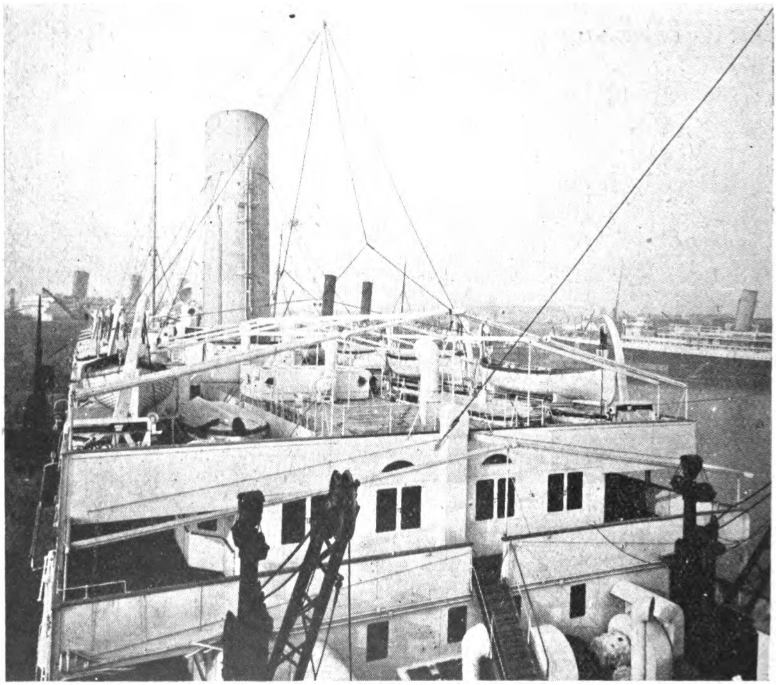


Fig. 211. *General View of D.F. Aerials of the R.M.S.P. "Andes."*

Leading-in of the Aerials. The simple shore method of supporting bare wires on telegraph insulators from the aerial base support to the wireless office has a number of disadvantages in the case of a ship installation. In the first place, the leading-in wires are usually much longer than on shore, and the aerial loops are smaller, so that an appreciable proportion of direct reception will result. Secondly, the leads frequently have to be run in exposed positions where there would be risk of damage to wires and insulators, both of a mechanical

nature and also due to weather. Furthermore, any such arrangement would be considered unsightly in certain ships. If, however, it is desired to use this type of lead-in, say, as a temporary expedient when cable is not available, the leads may be supported on either side of a plank as shown in Fig. 213. The transposition (page 218) is effected in this case by crossing the wires of each pair of leads so as to form diamond shaped loops and so arranging that the intersections of one pair of leads are intermediate between those of the other pair as shown in the figure.

It is difficult to carry the continuous length of aerial wire from the loops right through a lead-in of this type, and

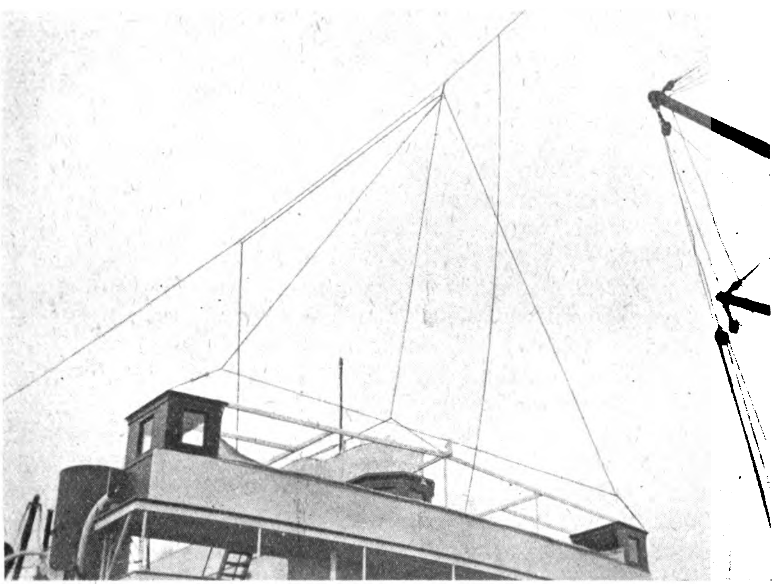


Fig. 212. *D.F. Aerials of the S.S.* "*Ballygally Head.*"

the silicon-bronze wire is too springy to allow the transposing to be carried out neatly. The lead-in may therefore be made of insulated cable, which has the additional advantage of rendering unnecessary an elaborate design of porcelain insulator, ordinary porcelain cleats serving the purpose quite well.

Shielding. Supported from the upper and lower edges of the plank is a shield of copper, zinc or galvanised iron sheet,

a portion of which is shown in Fig. 213, and this will serve both as an electrical screen and also as a protection against the weather. This screen need not be absolutely continuous, but it should be connected to "earth" at a number of points along its length.

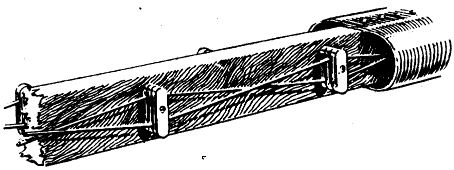


Fig. 213. *Screened Lead-in.*

Bulkheads. If the bulkhead through which the lead-in has to enter the wireless office is exposed to the weather the leads must be taken through suitable water-tight glands, and for this purpose it may be necessary to wrap them with insulating tape to make them the right size. It will probably be convenient to wrap the leads in pairs, care being taken to prevent the wires coming in contact with each other or with the metal work of the gland.

The above type of lead-in is essentially of a makeshift type, and the following method employing lead-covered cables has many advantages.

Lead-covered Paper Cables. A more practical solution of the problem of a satisfactory lead-in lies in the use of lead-covered paper insulated twin wire cable, constructed so as to have as small a capacity between the wires as possible, the necessity for which is discussed below. By adopting telephone cable practice and using dry paper loosely packed for the purpose of keeping the wires in position, the dielectric becomes chiefly air, and it is possible to construct a cable as shown in Fig. 214, the capacity of which is only 0·00086 mfd. between wires, per 100 ft. run.

The use of paper cable introduces the need for junction boxes at either end, an example of the outer ones being shown in Fig. 207 and the internal ones can be seen in Fig. 215, which shows the cables entering the W/T office. In fitting these junction boxes, all the usual precautions must be taken not to burn the compound with which they are filled, to ensure that all the soldered joints are thoroughly sound before the compound is put in, and never to leave the cable unsealed for any length of time.

In selecting a position for the cables to be run, the shortest route should be chosen consistent with safety from mechanical damage. A number of faults have been traced in ship D.F

installations to the fact that nails have been driven through the cables or the lead covering has been broken or chafed through.

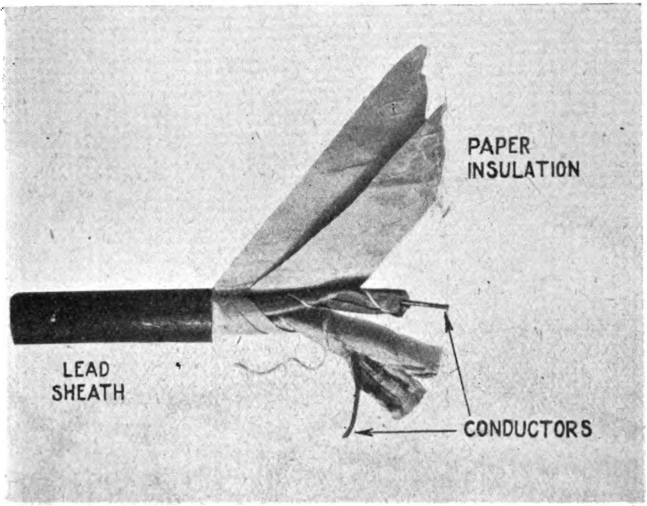


Fig. 214. *Lead-Covered, Paper Insulated Twin Cable for Lead-in.*
(About half full size.)

CIRCUIT ALTERATIONS NECESSITATED BY LONG CABLES.

When the distance between the wireless office and the aerials makes it necessary to employ great lengths of leading-in cable, trouble arises owing to the natural wavelength of the aerial circuit — which includes aerial loop, lead-in and radio-goniometer field coil—reaching a value which is within the range over which the set is designed to operate.

Fig. 216 shows in diagrammatic form the capacity of the two wires of the leading-in cable, and also the capacity of each wire to the lead sheath. These two capacities C_2 C_3 in series are connected in parallel with C_1 and therefore increase the capacity of the aerial circuit. Not only may the natural period of either aerial reach too high a value, but there is also the probability that since the loops are of different sizes and are differently affected by adjacent structures, the natural periods of the two aerial circuits will not be the same. If by any chance the leading-in cables are not made exactly the same length, difference in natural wavelengths will also occur. The result is that when the aerial system is tuned to

a wave approaching the critical value for either aerial, the phases and amplitude of the currents in the aerials become incorrect and the bearing is distorted.

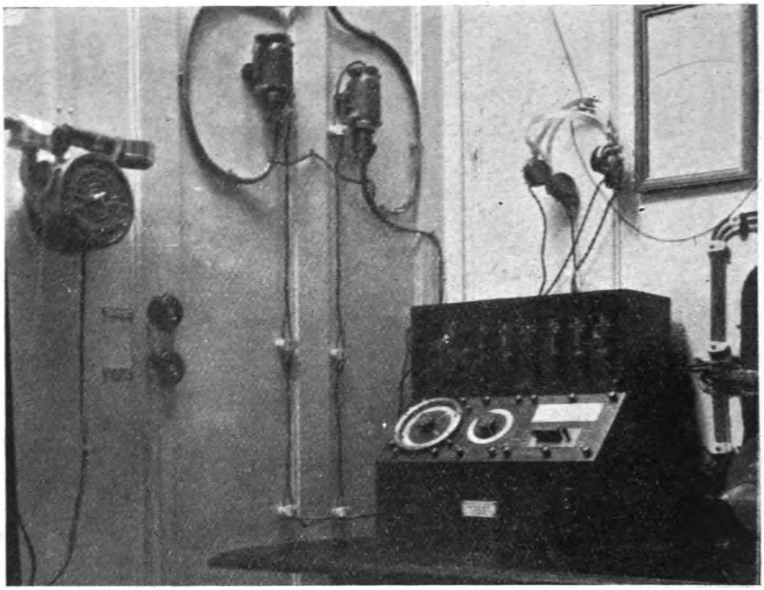


Fig. 215. *Interior of W/T Office, showing Internal Junction Boxes.*

Aerial Transformers. A solution of the above difficulty is the insertion of tightly coupled ratio transformers in the aerial circuit at the junction of the aerial loop and the cables, as shown in Fig. 217. By using transformers having a ratio of the order of 5 : 1, the high inductance winding being in series with the aerial loop, the natural wavelength of an average ship's aerial circuit, together with 100 feet of leading-in cable, can be reduced from 500 metres to just over 200 metres.

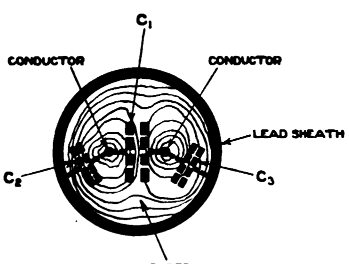


Fig. 216. *Self-Capacity of Lead-Covered Twin Cable.*

Owing to the low inductance of the secondary windings of the transformers it is necessary to have low inductance field windings on the radiogoniometer; but the decrease in number of turns enables

stranded wire to be used without taking up any more space, and the reduction in the losses in these windings compensates for those introduced by the ratio transformers.

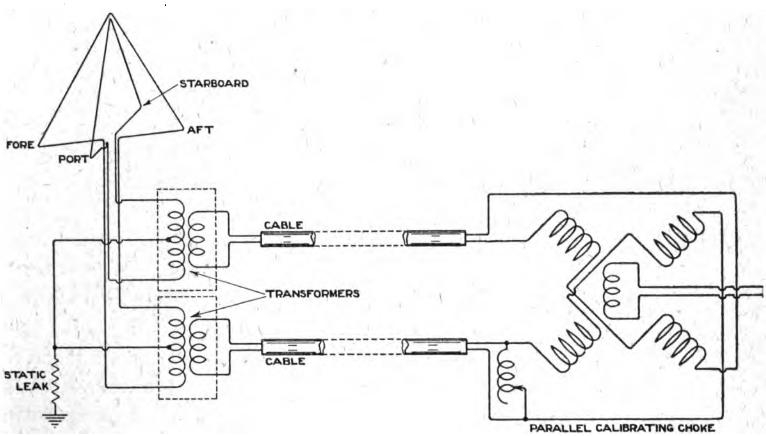


Fig. 217. *Arrangement of Ratio Transformers in Aerial and Lead-In*

Mid-point Connection. When the lead-in from aerial to D.F. instrument is very short, we have stated that it is usual to connect the mid-point of the field coils direct to earth (for figure eight reception) in order to protect the aerials and also eliminate " vertical " to a great extent. When, on the other hand, long cables are installed without ratio transformers, then in addition to the critical " loop " wavelength, the natural wavelength of the aerial system oscillating as an open aerial to " earth " may also become as great as 500 or 600 metres.

Now, provided that the loops are electrically symmetrical the earthed mid-point of the field coils should take care of any vertical; but in practice it is very rarely that the aerial loops are rigged under such ideal conditions as to be free from some degree of out-of-balance capacity of the type which would occur, say, in Fig. 205. Similarly the cables may not be well balanced, and the capacity C_2 (Fig. 216) may not be the same as that of the other wire C_3. Owing to out-of-balance capacity effects, either between a limb of the aerial and a deck-house, or due to a faulty cable or other similar causes, the distribution of the potential on the loop, when it is oscillating as an open aerial, is unsymmetrical and the electrical mid-point of the field coils is also no longer at the point where

the tapping is made. Under these conditions the two currents through the two halves of the field coils are unequal, and "vertical" reception occurs, thus defeating the original object of the mid-point connection.

Static Leak. For the reasons mentioned above, it becomes necessary to abandon the direct earth connection of the mid-point in certain cases and substitute for it a highly inductive impedance path to earth which acts as a leak for static charges on the aerial, but does not introduce this type of vertical, owing to the very great increase in wavelength and also the damping introduced in the open aerial circuit. This static leak is only included in the circuit when the apparatus is operating on the figure eight diagram; for sense determination, the phasing resistance and tertiary winding of the shielded transformer (Fig. 45) take its place.

When transformers are included in the lead-in, the static leak is connected to the mid-point of the primaries, and it becomes necessary to have a special aerial for the heart-shape circuit, though this need only be a small one and is easily rigged.

Parallel Connection of Calibrating Choke. When using ratio transformers between aerials and cables, it has been found that a more convenient method of calibrating is by means of a parallel adjustable choke, instead of the series chokes previously mentioned (page 261).

A MARINE DIRECTION FINDING INSTALLATION (MARCONI).

Fig. 218 shows a general view of a ship D.F. instrument, complete with amplifier and accessory apparatus. The set is intended for use with aerials of about 400 square feet area and upwards, and has a wavelength range of from 300 to 4,500 metres.

From what has just been said regarding the effects of long cables it will be understood that the actual circuit of a ship D.F. installation will vary to some extent with the existing conditions. In the set illustrated the normal circuit is shown in which aerial transformers are not used, and in which the mid-point of the field coils is connected to "earth," for direction finding. For "sense" the operating circuit is practically that of Fig. 45, and a "Stand-by" arrangement is also included.

With extremely long cables (200 feet) transformers are used, and it may sometimes be necessary to limit the range of the set to that given by one shielded transformer owing to the difficulty of adjusting the set for D.F., sense and stand-bi over a wide range of wavelength under these adverse conditions.

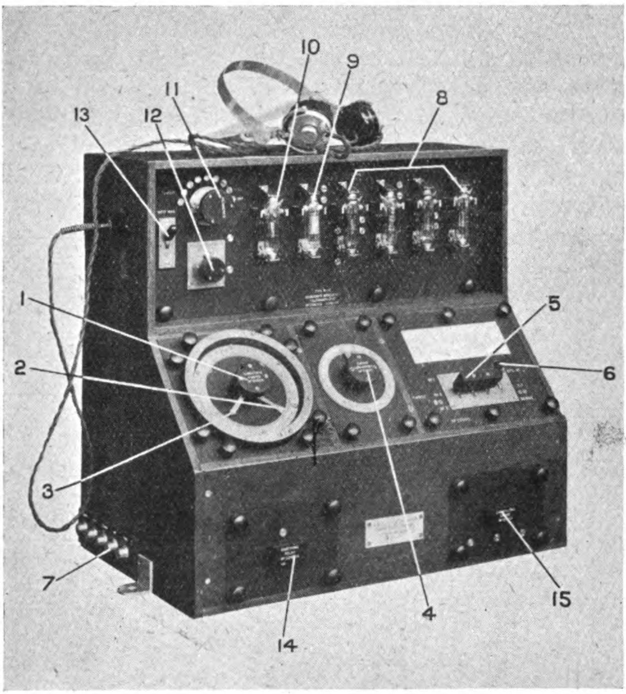


Fig. 218. *M-B-T Marine Pattern D.F. Receiver (Marconi).* (1) *Radiogoniometer.* (2) *Pointer for use on Cosine Diagram of Reception.* (3) *Pointer for Sense Determination on Cardioid Diagram of Reception.* (4) *Variable Tuning Condenser.* (5) *Transformer Range Switch.* (6) "*D.F.,*" "*Sense,*" "*Stand-By*" *Switch.* (7) *Terminal Block.* (8) *H.F. Amplifying Valves.* (9) *Rectifying Valve.* (10) *Note Magnifying Valve.* (11) *Valve Filament Rheostat.* (12) *Potentiometer for H.F. Amplifying Valves.* (13) *Note Magnifier Switch.* (14) *Earthing Relay.* (15) *Calibrating Chokes.* (*Refer also Figs.* 219 *to* 225.)

The instrument comprises four separately screened panels, namely, the radiogoniometer, tuning condenser, transformer and amplifier; also calibrating chokes and earthing relay.

In Fig. 219 the connections of the apparatus are shown, the particulars of the various components being as follows :—

The Radiogoniometer. (Fig. 220.) The mounting of the field coils and the construction of the field coil former of this instrument are very much the same as in the radiogoniometer shown in Fig. 192, except in certain details, but the dimensions are considerably less. Where the two field coils cross one another a layer of mica separates them in order to ensure good insulation between the aerial circuits. Each field coil is wound in two halves which are separated by about ¼-inch to allow a space at the centre of the end cheeks for the spindle of the search coil to project, and at the inner ends of each half-winding, *i.e.*, the centre of each complete field winding, a connection is brought out to a terminal.

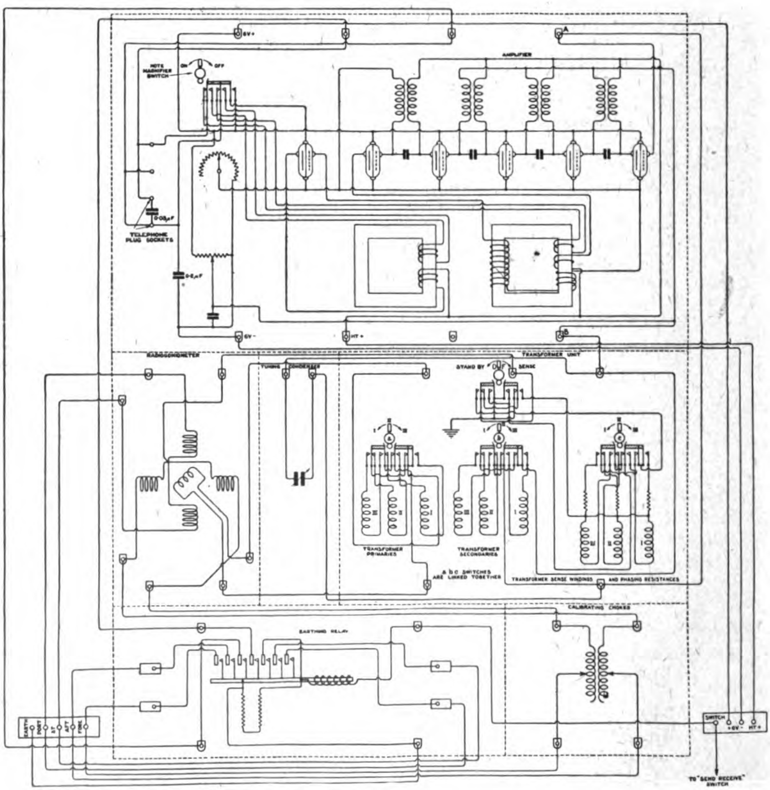


Fig. 219. *Circuit of D.F. shown in Fig.* 218.

Inside the fixed cylinder which supports the field coils, and separated from it by an air space of $\frac{1}{16}$ in., is a second ebonite cylinder, which is mounted on the spindle and on which is wound the search coil. The present practice in the design now described is to construct this search coil in two halves, which are connected in series and arranged so as to make an angle one with the other of approximately 45°. The actual angle is dependent on the structural details of the design, and may differ from the theoretical value of 45° by as much as one or two degrees. By this means certain coupling errors are reduced in the manner described on page 61.

The centre portion of the spindle is made of insulating material, so that the end connections of the search coil are attached, one to each end of the spindle, on which are mounted brass slip rings, the circuit being completed by gold wire brushes.

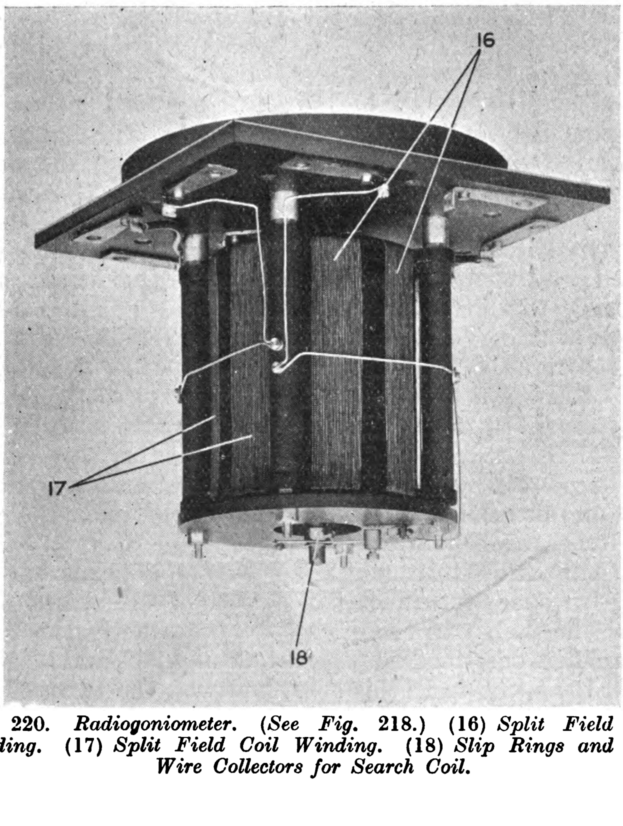


Fig. 220. *Radiogoniometer.* (*See Fig.* 218.) (16) *Split Field Coil Winding.* (17) *Split Field Coil Winding.* (18) *Slip Rings and Gold Wire Collectors for Search Coil.*

The upper part of the spindle carries the adjustable pointer and insulated handle for rotating the search coil and pointer. Since the spindle and hence the pointer are "alive," a sheet of triplex glass is placed over the scale to prevent the operator's hand from coming into contact with the pointer.

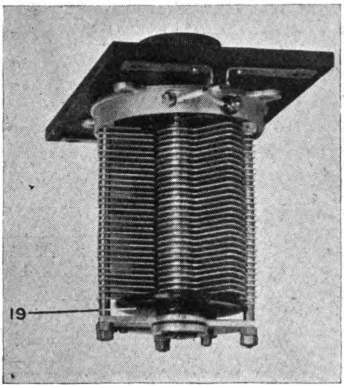


Fig. 221. *Variable Tuning Condenser.* (*See Fig.* 218.) (19) *Friction Disc.*

Tuning Condenser. (Fig. 221.) This follows the usual design of variable air condenser, but it is fitted with a brake disc, which prevents the moving plates from being rotated from the position of tune, owing to the motion and vibration of the ship.

Transformers and Switching Unit. (Fig. 222.) In order to obtain a wavelength range of from 300 to 4,500 metres, three shielded transformers are required, with isolating switches for cutting out of circuit the two not required. The transformers have three windings and, except for winding details, are exactly similar to the design shown in Fig. 179. The switching system is composed of vertical pattern telephone switchboard type keys, three of which are linked together by an ebonite bar, and can be thrown in three positions. One key is allotted to primary winding, another to secondaries and the third to the sense windings and associated phasing resistances.

On the right of the linked range switches is the stand-by-sense-D.F. switch, the operation of which is exactly the same as that described in connection with the shore installation on pages 247 and 251.

In the photograph are shown the three phasing resistances wound on mica slabs, supported immediately under the panel; the switches are behind the resistances.

The Amplifier Unit. (Fig 223.) The amplifier has four stages of high-frequency magnification, a rectifier and one note magnifier. The design of the circuit follows exactly the lines of the amplifiers described on pages 91, 95 and 252, and illustrated in Figs. 198 and 199. In this case, however, the two amplifiers and the control panel are combined in one unit for economy in space. The note amplifier switch performs the double

function of cutting out the note amplification and breaking the filament connection to the last valve, as shown in the diagram of connections.

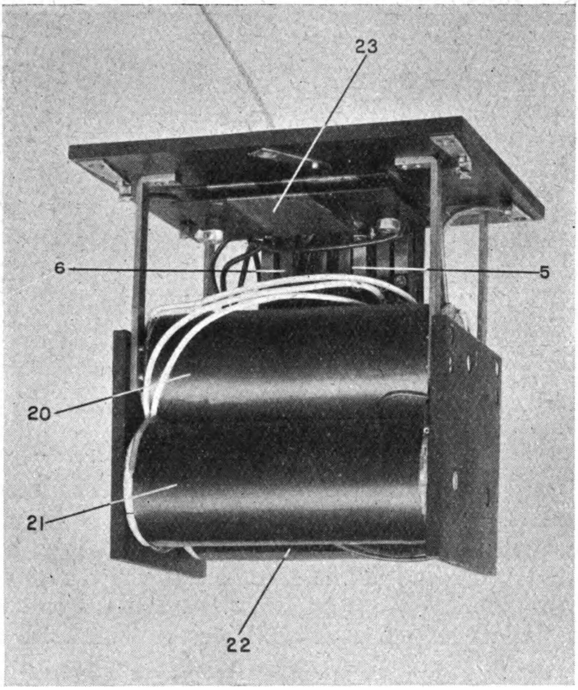


Fig. 222. *Transformer Panel.* (*See Fig.* 218.) (20) *Transformer Range I.* (21) *Transformer Range II.* (22) *Transformer Range III.* (23) *Phasing Resistances.*

The Earthing Relay. (Fig. 224.) The four leads from the aerials are earthed by means of this relay, and also the telephone terminals whenever the set is out of action. The relay is put into circuit by means of the change-over switch from ship's receiver to D.F. and is only operated when the "Send-Receive" switch is in the "send" position, so that the D.F. is thus protected when traffic is being passed on the transmitting aerial. An additional contact allows of an economy resistance being inserted in series with the winding of the relay, as soon as it operates. This permits of a comparatively large instantaneous current being used to ensure that the relay will not fail, but the "holding on" current

is only a fraction of the initial value and economises battery power, etc., during long periods of working.

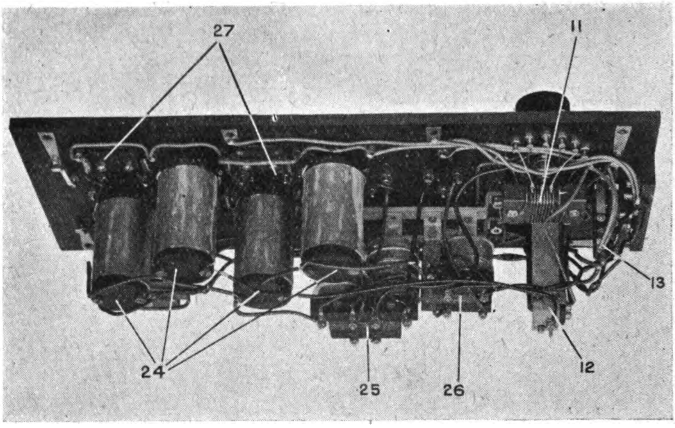


Fig. 223. *Amplifier Panel.* (*See Fig.* 218.) (24) *H.F. Inter-Valve Transformers.* (25) *Note Magnifier Inter-Valve Transformer.* (26) *Telephone Transformer.* (27) *H.F. Inter-Valve Condensers.*

The Calibrating Chokes. (Fig. 225.) In calibrating the ship installation it is convenient to reduce the size of the fore and aft aerial until the bearings are roughly true, and then to make final adjustment from the wireless office. The two adjustable chokes are wired in the leads from the fore and aft aerial to the radiogoniometer, and each has five tappings, giving a sufficiently fine adjustment for all ordinary purposes.

Lay-out of Apparatus. After what has been said on the above subject in Chapter 7, little remains to be added with regard to the ship installation, and in the case of the D.F. apparatus just described the question of lay-out hardly arises, as practically all the apparatus is already wired up.

ADJUSTMENT OF APPARATUS AND CALIBRATION.

Before any final adjustment is attempted it is essential that the rigging of the aerial be completed and the aerials stayed out to the exact positions which they will occupy when the vessel is at sea. The ship's rigging should also be complete, and any stays, etc., which have been slacked off in port should be replaced. In some

cases it will not be found possible to attain these conditions until the working of cargo has been finished—at any rate for the day—and it is therefore advisable to complete the D.F. installation as long as possible before the ship sails, in order that Sundays, holidays, meal hours and other periods when cargo is not being worked may be utilised for this most important part of the work. If everything goes smoothly, the whole operation may not take more than an hour or two; but unforeseen difficulties frequently arise, and it is worse than useless to allow the ship to start out on what may possibly be a six months' voyage with unsatisfactory gear.

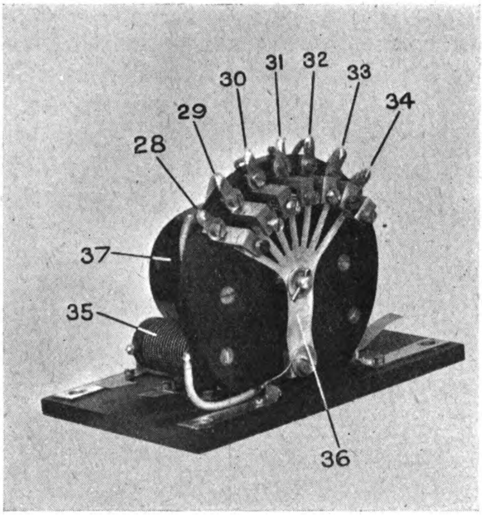


Fig. 224. *Earthing Relay.* (*See Fig.* 218.) (28) *Port Aerial.* (29) *Starboard Aerial.* (30) *Economy Resistance.* (31) *and* (32) *Telephone Short Circuiting.* (33) *Aft Aerial.* (34) *Fore Aerial.* (35) *Economy Resistance.* (36) *Earth Connection.* (37) *Yoke of Relay Magnet.*

Make a preliminary test of the radiogoniometer in the manner already described in Chapter 7, testing first one aerial alone and then the other to ensure that the two minima of the fore and aft aerial on the ordinary figure eight reception are exactly at 0° and 180°, and those of the thwartships aerial at 90° and 270°. For the purpose of these tests a wavemeter may be buzzed under the aerials, or actual signals may be used if available.

Next connect up both aerials and make a rough examination of the bearings of a few known stations, or of the wavemeter transmitter, although care must be taken that the coil of the instrument is always in a vertical plane and pointing towards the centre of the aerial system, or the resultant bearings may be distorted owing to the directional properties of the coil. *A wavemeter must never be used in this manner for actual calibrating.* As a test of whether the bearings are roughly correct, suppose the distant station has a true bearing of about 120°, then, if the observed bearing be anywhere between 110° and 140°, the connections of the aerials are probably correct. In moving the wavemeter round the aerial system, if the observed bearing also follows; it may be taken as conclusive. When, on the other hand, the bearings are totally incorrect, there is probably a cross connection somewhere in the lead-in, the tests and remedies for which will be found on page 320.

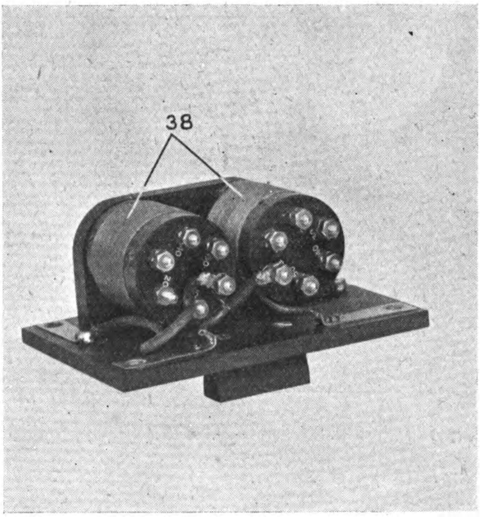


Fig. 225. *Calibrating Chokes.* (38) (*See Fig.* 218.)

TO FIND THE DIRECTION OF THE SHIP'S HEAD, and hence the true Bearing of a Transmitting Station, from the D.F. Bearing.

Since all the bearings taken on a ship D.F. are relative to the fore and aft line, it becomes necessary to find the direction of the ship's head before these relative bearings can be con-

verted to true bearings, and this applies equally to bearings taken during calibrating or navigating. The following instructions on the subject may be of use to wireless engineers making ship D.F. trials, although in some cases a navigating officer on board may volunteer to perform this part of the work, an offer which should be encouraged in Cases III. and IV. below.

Case I. When the Ship is alongside a Quay in any place where reliable Maps are obtainable. The line representing the quayside is found on the map, and its bearing from North measured with a protractor, observing the precautions already stated (page 209), regarding the direction of the meridians on an Ordnance Survey. This bearing will be that of the ship's head, except in the comparatively rare case when she is not parallel to the quay, a point which may be settled by inspection.

Case II. When the Ship is not alongside a Quay, or when for some reason her position only and not the direction of her head can be found from the Map. In this case the bearing of the ship's head may sometimes be found by applying the necessary corrections to the reading of the magnetic compass, as described below.

The Magnetic Compass. The needle, or system of needles, in the magnetic compass, when unaffected by local attraction, takes up a definite position in any place such that the North-seeking end points in a direction known as Magnetic North at that place.

Magnetic Variation. The direction of Magnetic North at any place differs from the direction of True North at that place by an angle called the magnetic variation. The variation is different at different places and is called East or West, according as the Magnetic North lies East or West of the True North. The variation at any place differs from year to year, but its value can be ascertained by reference to an Admiralty chart.

Deviation. Owing to local attraction, due to the magnetism of the iron and steel of which the ship is constructed, the compass needle may not be in the direction of Magnetic North, but to the East or West of it. This angle between the needle and the Magnetic Meridian is known as deviation, and is termed East or West according as the North-seeking end of the needle lies East or West of the Magnetic Meridian. The deviation is different for different positions of the ship's head.

Total Compass Error. The total compass error therefore equals the variation plus or minus the deviation, and before we can obtain true directions from the magnetic compass we must know the value of the variation at the place and the deviation for the position of the ship's head.

If the ship be several miles away from docks, etc., and from other ships the necessary corrections may be made in the following manner.

Ascertain the variation at the place from an Admiralty chart, and the deviation for the position of the ship's head from the deviation table, which generally will be found hung up near the compass to which it refers. Call *Easterly deviations and variations Positive* and *Westerly deviations and variations Negative,* and convert the compass bearing of the ship's head into degrees, as shown below :—

Bearings from		Example.	
N to E ..	No change	N39E	39°
E „ S ..	Subtract from 180° ..	S 24E	156°
S „ W ..	Add to 180°	S 53W	233°
W „ N ..	Subtract from 360° ..	N17W	343°

then the algebraic sum of the compass reading, deviation and variation will give the true bearing of the ship's head.

EXAMPLE.

Ship's head by compass ..	S36°E	(180°−36°)..	144°
Variation from chart ..	17°W	(Negative) ..	−17°
Deviation, from table ..	2°E	(Positive) ..	2°
Ship's head true			129°

EXAMPLE.

Ship's head by compass ..	N18° W	(360°−18°)..	342°
Variation	19° E	.. .. ..	19°
Deviation	$2\frac{1}{2}$°E	.. .. ..	$2\frac{1}{2}$°
			$363\frac{1}{2}$°
			360°
Ship's head true			$3\frac{1}{2}$°

Generally speaking, however, it will be found that, owing to the proximity of cranes, warehouses, other ships, etc., the deviation table is unreliable, and then either of the two following methods must be adopted for finding the total compass error.

CASE III. Same as II, but where Compass Error is Unknown. Two alternative methods are available, both of which involve the use of the azimuth mirror.

Method I. Obtain a reliable map, on a scale not less than 6″=1 mile, of the port in which the ship is lying and the loan of an azimuth mirror from the chief or navigating officer of the ship. Place the azimuth mirror carefully on the bowl of the standard compass and turn the prism by means of the milled head until the arrow is pointing upwards. Rotate the instrument until the pointer, which is seen over the compass card graduation, points to some distant prominent object ashore. Now, on looking down through the prism and slightly adjusting it the object will be seen reflected down on to the compass card. The azimuth mirror should then be moved round gently until the object and the pointer are seen together, and the coincident compass card graduation read off. Care must be taken not to touch the compass bowl or the azimuth mirror at the instant of taking the bearing; that the compass bowl is horizontal; that the compass card is quite steady and not swinging owing to the movement of cranes, etc., in its vicinity, and that the object is exactly coincident with the pointer.

Bearings of three or four such objects in different directions should be obtained and the results carefully noted. The position of the ship must then be fixed and the various objects of which bearings have been taken identified on the map. Pencil lines should be drawn on the map through the positions of the different objects ashore and the position of the ship. Another line should be drawn to represent the meridian through the ship, and from this line the bearings of the various objects may be measured with a protractor. The results may conveniently be tabulated as in the following example :—

Belfast, January 18th, 1920.

Ship's position .. .. Latitude 54° 36′ 30″ N.
Longitude 5° 55′ 00″ W.

Ship's head by compass .. N57E=57°

Object.	Compass Bearing.	True Bearing from Map.	Difference.
Albert clock ..	S59° W=239°	218°	−21°
City Hall ..	S54° W=234°	213°	−21°
Midland Railway Station ..	N34° W=326°	$304\frac{1}{2}$°	$-21\frac{1}{2}$°
B.M. Cave Hill ..	N 5° W=355°	334°	−21°
120-ton crane ..	N$79\frac{1}{2}$°E= $79\frac{1}{2}$°	58°	$-21\frac{1}{2}$°
Mean difference ..	..	..	−21°

Therefore, total compass error (*i.e.*, variation ± deviation)= −21° and ship's head true=(57°−21°)=36°.

Method II. For method of finding total compass error by observation and calculation of the sun's azimuth, see page 339, and compare with above method and example.

Case IV. Ship at Anchor (or Moored). Under these conditions the ship will almost invariably be swinging, and it will therefore be necessary to station someone at the standard compass to note the reading every time a D.F. bearing is taken, the necessary communication between the wireless office and the bridge being effected in the same way as when operating the D.F. at sea. This, of course, is dependent upon the compass error being known.

If the ship is in such a position that the compass is still under the influence of cranes, etc., the position of the ship must be found by horizontal sextant angles or by some other means, and the compass error determined by one of the foregoing methods.

CALIBRATION.

If equal-sized frame aerials be rigged on shipboard, one of them being in the fore and aft line, it will always be found that the bearings by D.F. tend to crowd towards the plane of this fore-and-aft aerial; thus, a station, the actual direction of which is 45°, would read, say, 30°, and similarly a station at 135° would read 150°. If under these conditions a series of bearings be obtained and the errors be plotted against *actual directions* a sine curve will result which is *negative* in the first quadrant, *i.e.*, from 0° to 90°, and changes sign in each succeeding quadrant. These quadrantal errors are due to the fact that the ship herself behaves as an aerial, and receiving from stations ahead and astern of her, re-radiates to the fore and aft aerial while the thwartship aerial is unaffected.

To make equal the resultant reception on both aerials it is necessary to reduce the area of the fore and aft aerial by shortening its base or adding choke coils in series or parallel with this loop.

When the amount of reduction in area of the fore and aft loop is estimated during the construction of the aerial, in order to save time during calibration, this reduction may be carried too far. This fact is at once made known when plotting an error curve, as the error is found to be *positive* in the first quadrant instead of negative, as is the case when the fore and aft aerial is too large.

Calibrating on Signals from known Transmitting Stations. For the purpose of calibrating by means of bearings on distant transmitting stations the most useful are those on the bow (45° and 315°) or quarter (135° and 225°), but satisfactory calibration can be carried out on quite a small number of stations, as shown by the following example.

Suppose bearings have been obtained on four stations and tabulated as follows :—

Station.	D.F. Reading.	Bearing of Station from Ship's head (from Gnomonic chart).	Error.
FL	$22\frac{1}{2}°$	$30\frac{1}{2}°$	— 8°
GRL	$43\frac{1}{2}°$	$53\frac{1}{2}°$	— 10°
FUT	$30\frac{1}{2}°$	40°	— $9\frac{1}{2}°$
MPD	$66\frac{1}{2}°$	73°	— $6\frac{1}{2}°$

On plotting these results out as shown in Fig. 226 they are quite enough to show that there is a maximum error of about —10° in the first quadrant, to compensate for which the fore and aft aerial is shortened by, say, 2 feet, by making two loops (see Fig. 202), each 1 foot in circumference on either side of the aerial centre support. When the area of the loop has been reduced by a succession of operations such as those just described until the maximum error is within a few degrees (and still negative in the first quadrant) the fore and aft aerial can be

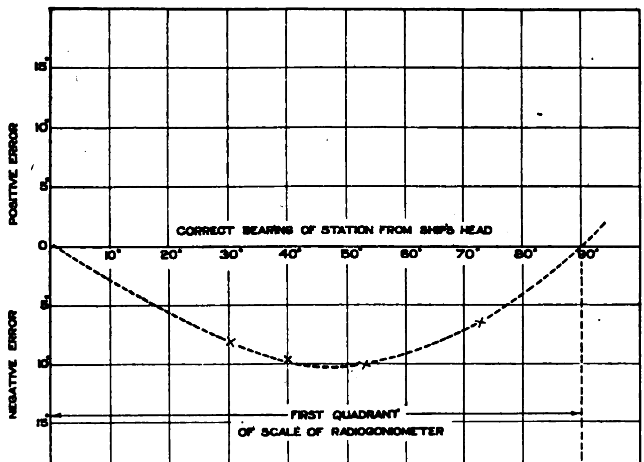


Fig. 226. Error Curve of Uncalibrated Ship D.F. Installation.

re-made to the new dimensions and final calibration carried out by means of the calibration chokes from the wireless office. Care must be taken that the same amount of choke is inserted in each limb of the fore and aft aerial.

Calibration when the Ship is at Anchor or Moored. In cases where the ship lies near large cranes, alongside warehouses or within a mile or so of large gantries, errors other than those introduced by the hull of the ship are to be expected, and under these circumstances satisfactory calibration will be impossible. It will frequently be found that the reduction of the fore and aft aerial does not give the desired calibration, and, on occasion, the bearing of a transmitting station is found to vary with the movement of a travelling crane near the ship. In such cases the calibration must be postponed until the ship moves away from the place and is either anchored or under way on a steady course.

When the ship is at anchor the D.F. readings of the transmitting stations are tabulated against the corrected compass readings, and the true bearings of the transmitting stations according to the D.F. are found by the following rule :—

$$\begin{array}{c}\text{True Bearing}\\ \text{of Station}\\ \text{by D.F.}\end{array} = \left(\begin{array}{c}\text{D.F.}\\ \text{Reading.}\end{array} + \begin{array}{c}\text{Corrected}\\ \text{Compass}\\ \text{Reading.}\end{array}\right) - \begin{array}{c}360^\circ\\ \text{(If result greater}\\ \text{than } 360^\circ.)\end{array}$$

Observations may be tabulated thus :—

Station.	D.F. Reading.	Corrected Compass Reading.	True Bearing of Station by D.F.	True Bearing of Station from Chart.	Error.
GMH	275°	336°	251°	$249\frac{1}{2}$°	$+1\frac{1}{2}$°

(Where $275^\circ + 336^\circ - 360^\circ = 251^\circ$).

Ship under Way. A similar procedure is necessary when the ship is under way, but the problem is complicated by the fact that the ship is moving, so that her position has to be plotted out on the chart for each bearing and the bearing of the distant station measured off. The true bearing of the ship's head in these circumstances will always be taken from the compass after applying the corrections for variation and deviation.

In carrying out calibration after a ship has sailed, care must be taken not to interfere with the ship's wireless service if there is any chance of it being required, and in any case it is unlikely that any extensive help will be obtained from the bridge until after the pilot has left, unless circumstances are

very favourable. It should be remembered that calibration is practically impossible when the ship is under way, unless she is on a set course, and this condition rarely exists until some considerable time after she has sailed, and even then, if the ship yaws at all or swings off her course, as she usually does, calibration becomes a laborious, intricate and temper-testing operation.

Special Transmitters for Calibration. It has been mentioned that the calibration of a shore station is sometimes effected by making simultaneous optical and wireless bearings on a mobile transmitting station within a few wavelengths of the D.F. station. Conversely, when a considerable number of ships are being fitted with D.F. installations and calibrated at the same port, it may sometimes be worth while to have a special low-power transmitter on shore, in an exposed position. To gain the best results the ship should be either at anchor or moving very slowly, and in any case she should be in such a position that the transmitting station is on the bow or quarter. If time permits of the ship being swung, as is done in the case of magnetic compass trials, extremely good results could be obtained. Some of the advantages of the special calibrating station are lost if the ship be in a position from which the station is not visible, as the accuracy of the work depends largely on the fact that optical bearings can be taken by means of a bearing plate or azimuth mirror, at the same instant as the D.F. bearing, and thus the compass error is eliminated.

TAKING BEARINGS.

On the receipt of instructions to take bearings on one or more stations, the telegraphist acknowledges the order and takes steps to get into communication with the stations, unless they already happen to be engaged on traffic. As soon as the required station is heard, a stand-by signal—say, two strokes on the gong—is sent to the bridge as a warning to hold the ship as steady on her course as possible and to be ready to note the compass reading on receipt of further gong signals. The gong switch and telephone to the bridge can be seen in Fig. 215.

In the case of a rotating frame installation on board ship, the frame is sometimes located vertically over a magnetic compass and the two instruments are so combined that the D.F. pointer operates on the compass card, enabling true

bearings to be obtained direct (47). The obstacles, however, in the path of obtaining any greater accuracy with this arrangement than with the separate instruments and gong signalling would appear to be very considerable. The ideal combination, as already stated, would doubtless be that in which the scale of the direction finder was controlled by a gyro compass, or failing that, in which a gyro compass repeater dial was fitted alongside the direction finder.

To return to the gong signal method, the actual taking of the bearings does not differ from the methods already described for the shore D.F., but the practical difficulties are greater, especially in bad weather. When the ship is yawing it becomes difficult to get consistent swing bearings and practice is necessary and also experience of the behaviour of the ship in various types of seas before bearings can be obtained with assurance. As a reading is taken on the D.F. a signal (one stroke) is sent on the gong and the telegraphist and the person at the steering-compass both log their readings and the time. As long as the station continues to transmit, further bearings are taken, gong signals being sent each time until about five have been obtained. If the bearings are taken at very short intervals there is no necessity to log the time of each, but successive readings should be numbered 1, 2, 3, etc., by both the telegraphist and the helmsman.

When special forms are supplied for logging the bearings, space may also be left for the latitude and longitude of the station to be filled in by the telegraphist. There is an advantage in doing this, in that sometimes there are two wireless stations near the same port, or the name of the wireless station may be different from that of the port which it serves, and in such cases confusion might arise. The telegraphist has full information on all these matters and is in a better position to know the details of the station on which the bearings were taken.

Sometimes it may happen that when one bearing has been obtained on station A, say, this station stops transmitting, and station B is heard. In such a case it is advisable to take bearings of B and return to A later, when he is heard again. So long as the gong signal is sent for each reading and the successive readings are numbered and also timed where possible, there is no chance of confusion when the log sheets are handed in to the bridge. An effort should be made on the part of the wireless staff and the navigating officers of

the ship to arrange a routine in connection with the D.F. work, when all possible sources of confusion can be given special attention and the whole operation brought to a state of efficiency.

Any bearing which seemed a doubtful one should be marked to this effect, so that if it differs widely from the remaining ones on that station it may be neglected rather than averaging it in with the remainder.

As soon as the work is completed a finishing signal (say, three strokes on the gong) should be sent to the bridge and the log-sheets prepared and sent in.

CHAPTER 9.

THE AIRCRAFT D.F. INSTALLATION.

The Problem of Aircraft Navigation. With one or two fortunate exceptions, all the problems of the ship D.F. installation are repeated in an exaggerated form in an attempt to navigate aircraft by a D.F. installed in the machine, and additional difficulties are also met with which have taxed to the utmost the ingenuity of those engaged in this field of the work. Amongst the factors which militate against accurate work may be mentioned the very cramped space in which the wireless apparatus has to be operated, the prevailing noise, and also the difficulty of maintaining the machine steady on a course during the operation of taking the bearing. In addition to these points, the great speed at which aircraft travel, as compared with a ship, complicates the problem of navigation by cross bearings, as the distance covered between successive bearings may be a matter of miles.

Solutions of the problems have been sought in a variety of directions, with the result that at the present time several systems of direction finding are in use in aircraft, each system possessing disadvantages which make it difficult to suppose that finality has been reached. The technical difficulties will become more apparent on considering an attempt to use the simple rotating frame D.F. for aircraft work.

The shore station rotating frame has an average size of about 12 feet by 12 feet, and may be considerably larger than this, so that a great reduction in the area of the frame is one of the first modifications necessary. The largest rotating frames used in aircraft have not exceeded 5 feet by 4 feet, and even then the machines in which they were installed were exceptionally large ones. The valve amplifier, however, enables signals to be received on multi-turn frames only 4 or 5 square feet in area, and it will be assumed that space has been found for such a coil and the apparatus has been installed inside the fuselage.

Errors in Bearings. The interior of the fuselage of an aeroplane is probably one of the last places in which a small rotating frame could be expected to record accurate bearings

of distant stations. The proximity of the engines and tanks introduces screening, and, in addition to this, the whole machine is a network of wires forming stays, controls and the ignition system of the engines. It is usual to bond all the stay wires to an "earth" trunk which is in contact with the framework of the engines and tank. This is done to prevent sparking during wireless transmission, but it has the effect of giving the aeroplane the characteristic of the hull of a ship and produces definite quadrantal errors of the same nature, having their minimum values fore and aft and thwartships.

Magneto Noise. Unless special precautions are taken, the electrical interference from the ignition system of the engines will produce a noise in the telephones which completely obscures the loudest signals. To each spark plug there is attached a considerable length of high-tension cable, which, with the spark gap and magneto, forms a low-power transmitting installation which radiates short waves of a highly damped nature. That this radiation from the ignition system is a real trouble may be gauged from the fact that bearings have been taken by a ship D.F. station of an aeroplane a mile distant, and which was not fitted with a wireless transmitter, the radiation from the ignition system being enough to give audible signals. It is not unusual to have as many as twenty-four sparking plugs on a large twin engine machine, and the problem resolves itself into eliminating the jamming from twenty-four plain aerials, all sparking in close proximity to the receiving aerial.

Means have been found for reducing this interference to an almost negligible amount, but a certain proportion is generally present in the case of frame-aerial reception, and it is clearly desirable to have a receiving system capable of producing the loudest possible signals from the beacon stations so that slight local interference will have less effect.

Engine Noise. In addition to the electrical noise there is also the engine exhaust to be considered, and the usual way to combat this is to have the telephone receivers sewn into the flying helmet. By taking the trouble to have the pockets containing the ear-pieces sewn to the helmet at exactly the right place, and by keeping the telephone pressed tightly to the ears, the bulk of engine noise can be avoided.

SYSTEMS OF AIRCRAFT D.F.

The simple rotating coil, therefore, suffers from the disadvantage that, if made small enough to be installed in the fuselage of the average aeroplane, the signals will not be strong enough for practical D.F. work through the electrical and other interference, and particularly since the simple frame operates near the zero of signal strength.

Wing Coil System. An early method of solving the space problem was to have the aerial loop fixed relatively to the framework of the machine, which is itself swung for the purpose of taking a bearing. In this case the aerial is secured to the wings, as shown in Fig. 227, and an area of 100 or 150 square feet may be obtained without difficulty. The name "wing coil" is given to such a construction as distinct from a "fuselage coil," which is rotatable and mounted in the interior of the fuselage.

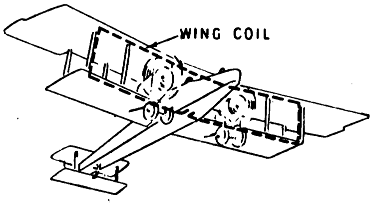


Fig. 227. The Wing Coil Method of D.F.

A D.F. system of this type is best adapted for the purpose of flying towards an objective where a wireless transmitter is working. The method of navigating is illustrated in Fig. 228. When flying directly towards the station no signals can be received, since the wing coil is at right angles to the direction of propagation of the waves. The fact that signals are heard at any time indicates that the machine is off its course, and on taking successive swing bearings to the port and starboard and matching the strengths of signals, the mid-point can be estimated and the course reset.

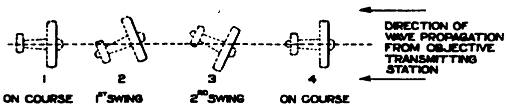


Fig. 228. Swing Bearing using the Wing Coil.

Drift. In the case when a strong cross wind is blowing, the use of the D.F. alone, as a means of flying to an objective transmitting station, has certain limitations. In Fig. 229 the machine is taken as having an air speed of 100 m.p.h., and there exists a cross wind of 20 m.p.h. In such a case the resultant speed of the machine will be a combination of that

due to the wind and the relative air speed of the machine, as represented by the vector OC. The important point to notice is that the machine does not now head in the direction of the actual course taken.

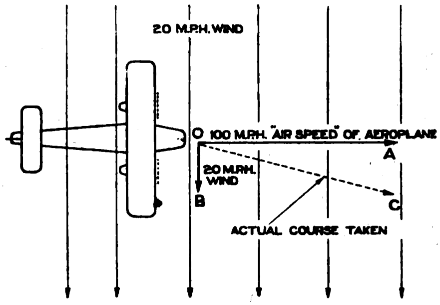


Fig. 229. *Drift of Aeroplane due to Wind on Beam.*

In these circumstances the use of a D.F. results as shown in Fig. 230. At (*a*) the aeroplane is taking the correct course for flying direct to the objective, namely, heading slightly into the wind. If now the machine is headed by D.F. straight for the transmitting station, as at (*b*), then the wind will cause a drift to some position (*c*), when the course will again have to be altered to bring the machine "head on." This process continues until, depending on the wind velocity and the duration of the flight, the machine may actually approach the objective eventually, flying up-wind, as at (*g*). (120.)

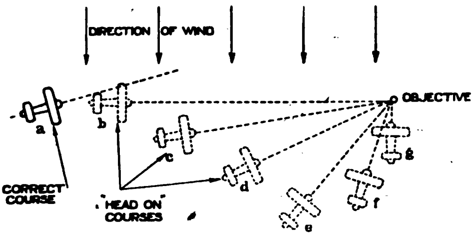


Fig. 230. *Effect of Drift when Flying Head-on to Transmitting Station Objective.*

The fact that the ground may be obscured by darkness or fog makes it important to take this drift into account, as it assumes far greater proportions than the corresponding drift at sea, due to tides and currents, and an aeroplane may be deviated from its correct course to a dangerous extent.

Magnetic Compass. The presence of drift can at once be detected if the magnetic compass course is noted corresponding to each "head on" course, as found by D.F. The magnetic compass course should remain constant, and any tendency towards a gradual alteration would indicate a drift, as shown in Fig. 230 and the machine would be flown several points off the "head on" course, as at (*a*).

Position Finding by the Wing Coil System. The navigation of an aeroplane by cross bearings on a number of transmitting stations when using the wing coil system, involves the turning of the machine " head on " to each station in turn and noting the magnetic compass course corresponding to the position of zero signal strength.

THE ROBINSON D.F.

It was in an attempt to avoid the necessity for turning the machine off its course every time a bearing was taken, and at the same time to ensure ample signal strength, even in the neighbourhood of the minimum, that the above system was devised, the principle of its action having been already described on page 45.

Types of Coils. As in the case of the simple rotating frame D.F. mentioned on page 28, the coils of the Robinson D.F. may be either " box " or " pancake " in form or a combination of the two types. Fig. 231 shows a " box " form

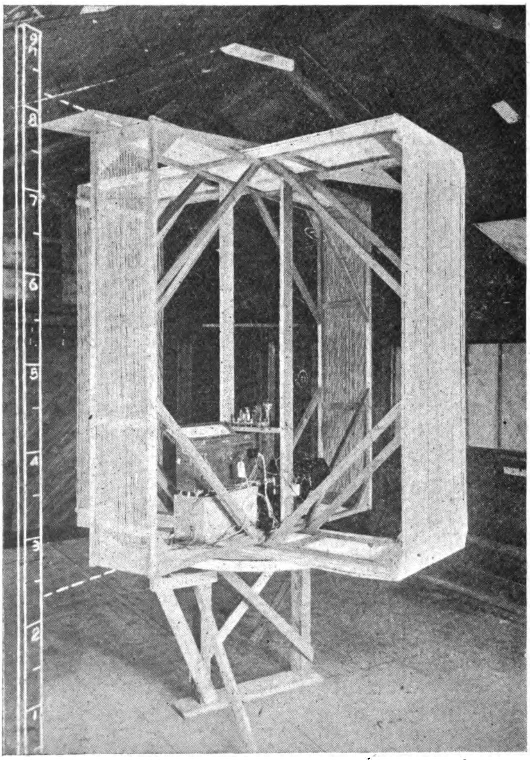


Fig. 231. *Robinson D.F. using Box Type Coils*

coil, together with the receiver mounted inside the coils and Fig. 232 illustrates a " pancake " coil D.F. installed in the fuselage of a Handley Page aeroplane, the fabric of which has

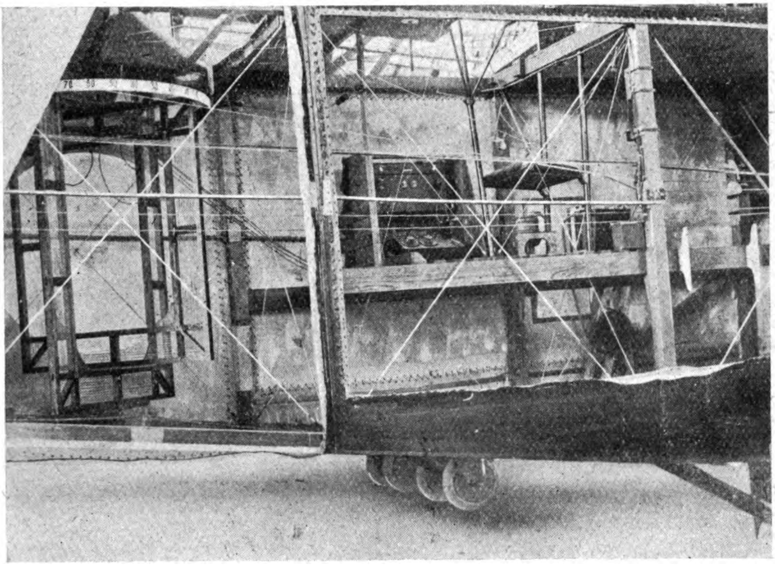


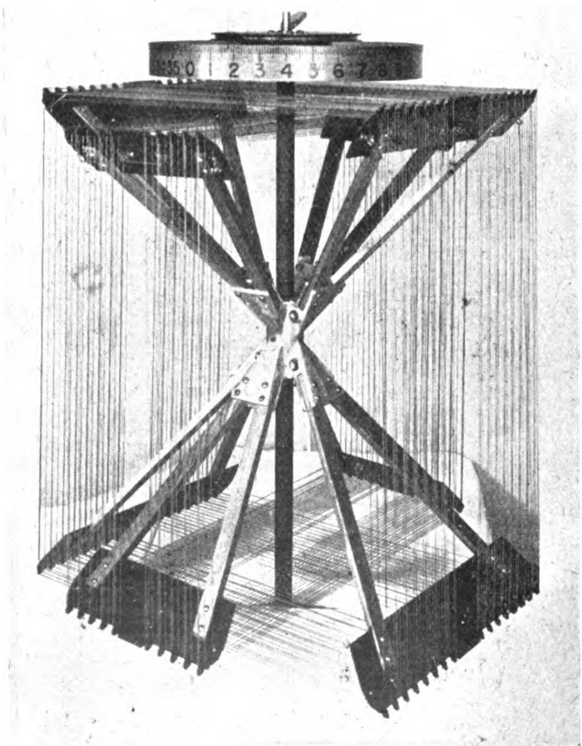
Fig. 232. Robinson D.F. using Pancake Type Coils. Mounted in Fuselage of Handley Page Aeroplane.

been cut away to show the D.F. and receiving apparatus. Fig. 233 shows a combined " box " and " pancake " construction adopted by the United States Navy for use in their " N.C." flying boats and Class " C " dirigibles (84). The special virtues of the last mentioned coil construction have already been discussed on page 37.

Relative Sizes of Main and Auxiliary Coils. In each of the D.F.s illustrated above, the coil having the greater area-turns is the auxiliary coil. It has been found in practice that if the area-turns of the auxiliary coil are made equal to those of the main coil, the change in signal E.M.F. corresponding to a movement of 1° of the auxiliary frame from the minimum position is 3.5 per cent. When this ratio of area-turns is increased to 10 (the auxiliary coil being the greater) the signal E.M.F. variation for 1° swing is found to be 35 per cent., or, in other words, the sensitiveness improves as the system approaches a simple frame. Under these conditions the superimposed signal due to the main coil becomes very weak and

the increased sensitiveness is in danger of being more than nullified by engine noise and other types of interference. A compromise must therefore be effected, and the Royal Air Force found that a ratio

$$\frac{\text{Aux. coil area-turns}}{\text{Main coil area-turns}} = 2.5$$ rendered the apparatus sensitive to within about 1° and gave the best all-round results (49), (59).



Jour. Inst. Radio Engineers.

Fig. 233. *Combined Box and Pancake Type Coils used by U.S. Navy.*

The question as to whether the zero minimum of the simple frame is more or less easy to detect than the minimum with a superimposed steady signal, has been the subject of some controversy. In an aeroplane in flight there may be enough noise to render the signals in the neighbourhood of the zero

minimum quite inaudible over a considerable arc of the scale. In the circumstances, the steady signal due to the main coil would undoubtedly render the signals audible, but whether the changes in intensity for a given swing could be measured any more accurately than by taking wider swings about the zero minimum is largely a matter of training and individual preference (49), (50), (59), (128).

The Robinson D.F. adapted to the Wing Coil System. Owing to the impossibility of providing space for fuselage coils in the average aeroplane, the Robinson system has been adapted to wing coil working, as shown in Fig. 234, which illustrates the usual method of rigging the two aerials. The main coil is attached to the wing struts and wings, and rigged fore and aft and in some cases the coil is split into two parts, one being placed on each wing and the two halves connected in parallel as shown. The auxiliary coil may either be the full length of the span between the outer struts of each wing or, in the case of a machine with folding wings, a separate coil is mounted on each wing and the two connected in parallel, as in the case of the main coil. (84.)

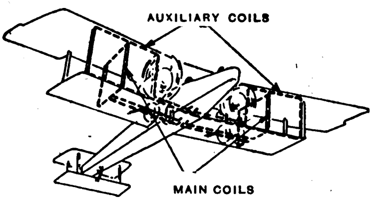


Fig. 234. Robinson D.F. adapted to Wing Coil Method of D.F.

It still becomes necessary to turn the machine off its course for taking bearings of stations which are not exactly ahead or astern.

THE BELLINI-TOSI SYSTEM ON AIRCRAFT.

At the time when the urgent necessity for a practical aircraft D.F. system arose during the European War, the B-T system was still operating with tuned aerials which had to be maintained in accurate balance. Furthermore, no solution of the problem of magneto noise had been found, and a system working on a zero signal method was at a serious disadvantage when operating under the prevailing conditions of noise from electrical interference.

With the advent of the aperiodic aerial system and the elimination of magneto noise, the B-T system became at once adapted to aircraft work and combines, in many respects, the advantages of the wing coil and fuselage coil systems. Large aerials can be rigged, giving ample signal strength, and a radiogoniometer of very small dimensions fitted alongside

the remainder of the wireless telegraph and telephone controls enables bearings to be taken of any transmitting station without deviating the machine from its course.

An Aircraft D.F. Installation (Marconi). The diagram of Fig. 235 and the photograph of Fig. 236 illustrate the application of the M.-B.-T. aperiodic aerial system for use in a

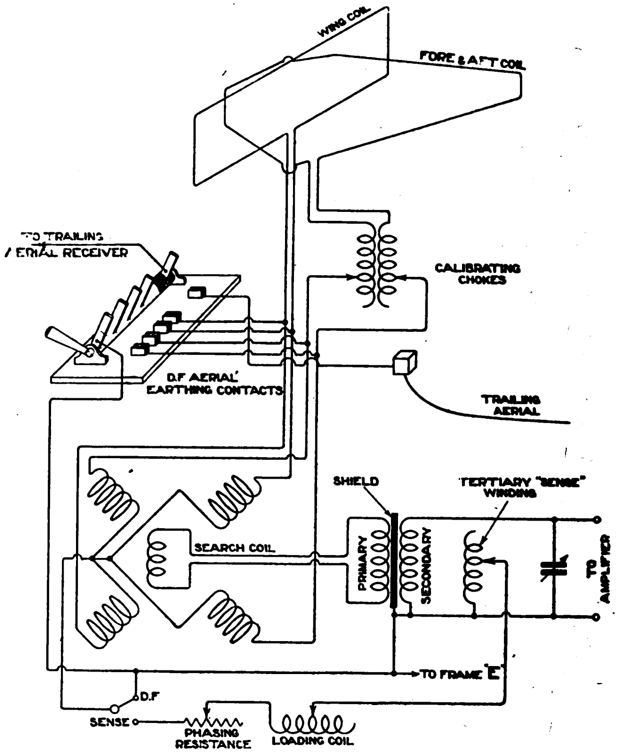


Fig. 235. Circuit of M-B-T Aircraft D.F.

Short flying boat. The circuit employed is almost identical with that described in the last chapter in connection with the marine D.F. The apparatus panel in Fig. 236 contains the whole of the wireless equipment of the machine, including the transmitter and receiver for telegraphy and telephony, and it is arranged for operation by the navigator. The following is a brief description of the installation :—

Calibrating Chokes. Series calibrating chokes are fitted, after the aerials have been rigged and tested, in series with which every loop is found to have the greater receiving power.

The method of using the chokes for calibrating purposes has already been described on pages 260 and 293.

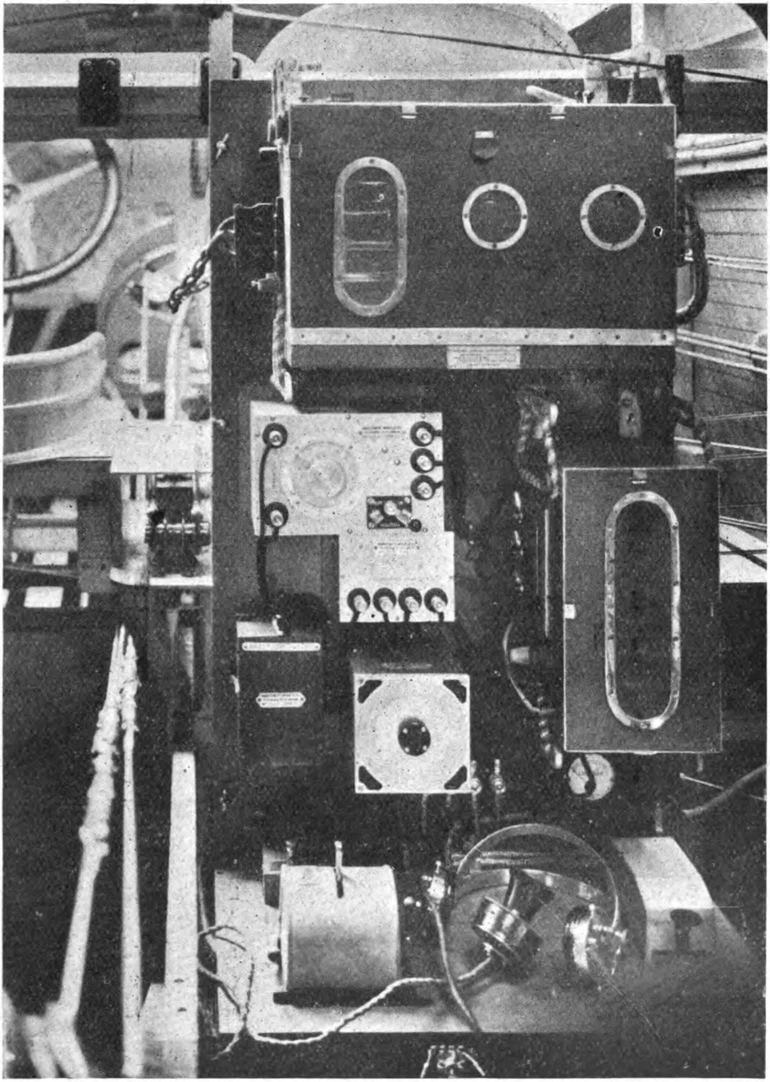


Fig. 236. *M-B-T Aircraft D.F. Installation* (*Marconi*). (*See Key Diagram* 236*a and circuit Fig.* 235).

Receive-D.F. Switch. This switch is seen on the left-hand side of the panel and performs a number of functions, which include :—

(1) Changes over the battery leads and telephones from the amplifier used with the trailing aerial reception to the D.F. amplifier. (These connections are not shown in Fig. 235.)

(2) Disconnects the trailing aerial from the receiver when the D.F. is in use.

(3) Connects all the four ends of the D.F. loops to the "earth" trunk, when the transmitter is in use.

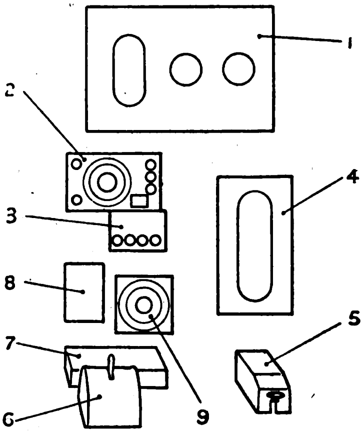


Fig. 236 (*a*). *Key Diagram for Fig.* 236.

(1) *Telegraph and Telephone Transmitter and Receiver.*
(2) *D.F. Tuning Unit.*
(3) *Calibrating Chokes.*
(4) *D.F. Amplifier.*
(5) *Transmitting Key.*
(6) *Remote Control for* (1).
(7) *H.T. Battery.*
(8) *Change over-switch, Trailing Aerial Receiver* (1) *to D.F. Receiver* (4).
(9) *Radiogoniometer.*

Radiogoniometer. This is similar in pattern and electrical design to that shown in Fig. 220, but it is considerably smaller and is totally enclosed in an aluminium shielding case.

Shielded Transformer. A wavelength range of from 600 metres to 900 metres is provided for, and a single transformer only is required. This transformer is similar to the one shown in Fig. 179, the sense winding being mounted on a removable former in order that adjustments may be made to the number of turns when making running tests after the installation of the set.

Tuning Unit. To provide for the change in "vertical aerial" tuning which results from varying the turns on the tertiary winding of the transformer, an additional loading coil is provided and is connected in series with the sense winding

and the phasing resistance. These three pieces of apparatus, together with the tuning condenser and " D.F.-Sense " switch, are all mounted in a single unit.

Amplifier. Owing to the great reduction in signal intensity when on frame reception, as compared with trailing aerial reception, it is necessary to use greater magnification. The amplifier on the right-hand side of the panel is very similar to that shown in Fig. 223, except that it comprises six high-frequency stages, a rectifier and a note magnifier, and the whole construction is much lighter and more compact. The weight of the D.F. apparatus mounted on the panel, including batteries, is about 30 lbs.

TESTING AND CALIBRATION OF THE AIRCRAFT D.F.

In the case of fuselage coils or the M-B-T system, it is necessary to plot an error curve after the installation of the apparatus and to calibrate the set. It is not a difficult matter to obtain a large number of bearings at different points on the D.F. scale by the simple process of swinging the aeroplane through a known angle, as measured with a sextant or on an aerodrome compass bed, and listening to signals from a single transmitting station. Calibration carried out on the ground in this way is usual sufficiently accurate.

It is generally found that the errors traceable to screening from the engines or tanks are not nearly so marked as the quadrantal errors, and in the case of fuselage coils it is usual to supply an " error chart," from which a correction is obtained for every bearing taken, just in the same way that a deviation table is supplied with a magnetic compass.

The calibration of the M-B-T installation by means of calibrating chokes is precisely the same as in the cases already described on pages 260 and 293.

Advantage should be taken of air tests whenever these can be arranged, and if the trailing aerial connection is not controlled by an automatic switch, care must be taken that this aerial is always disconnected during D.F. work. For the adjustment of the sense circuit of the M-B-T installation it is quite essential that test flights should be made. Unlike the case of the ship or shore station, there is no definite earth below the aerial system, when the machine is in the air and the " earth " connection for the mid-point of the radiogoniometer field coils is made, via the sense winding of the trans-

former, to the framework of the engines and the earth bonding of the machine. The result of this may be that whilst a satisfactory heart-shape diagram of reception is obtained on a ground test, the conditions are totally altered when the machine is in the air.

METHOD OF RIGGING WING COILS AND M-B-T AERIALS ON AIRCRAFT.

In designing the frame aerials for use on aircraft it must be borne in mind that the methods of rigging them are very different from those in the case of ship or shore stations. Bare wire construction, with porcelain insulators or cleats, is replaced where possible by rubber-covered flexible wire, which is secured to the spars and fabric of the machine in a manner which will offer the minimum wind resistance. It is advisable to confer with an aircraft designer in all matters of the adaptability of shore apparatus to aircraft uses. An aeroplane is built, from first to last, to be as light as possible compatible with mechanical safety, and no apparatus or fittings which are unduly heavy or which may reduce the strength of any of the members of the structure can be used.

The type of wire used for the wing coils is usually a flexible pattern similar to ordinary lighting flexible, but rubber-covered instead of being braided. The United States Navy use a conductor of 16/33 S.W.G. wires. This wire is attached to the wings or struts by being covered with tape, which is glued to the fabric and finally coated with the usual " dope " varnish of cellulose acetate. Single-turn coils are usual in the M-B-T system, but the multi-turn coils of the Robinson wing coil systems are mounted in a similar way, a number of wires being laid up, suitably spaced in a specially constructed linen tape and then glued and doped. If the D.F. is being installed at the factory during the construction of the machine it is preferable to run the wing aerials in the internal framing of the wings, before the fabric is put on.

The M-B-T Fore and Aft Aerial. Unlike the small main coil of the Robinson D.F., it is necessary that the fore and aft M-B-T aerial should be almost as large as the wing aerial, and this may necessitate a bare wire construction. Fig. 237 shows the method of rigging the fore and aft aerial on a " Short " flying boat, a certain amount of bare wire being used.

In exceptional cases, where very long distance working is required and it is desired to have the maximum possible size

of aerial, a construction similar to that shown in Figs. 238 and 239 may be used in which short masts are rigged both fore and

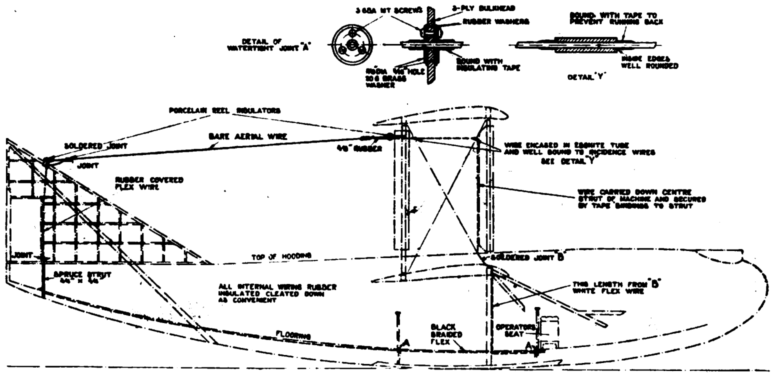


Fig. 237. *Rigging of M-B-T Fore and Aft Aerial on "Short" Flying Boat.*

aft, enabling this aerial to be almost as great in area as the maximum wing aerial. Such a scheme is undesirable, particularly with regard to the fore mast, as any mechanical failure here might allow the aerial wire to come into contact with the propellers.

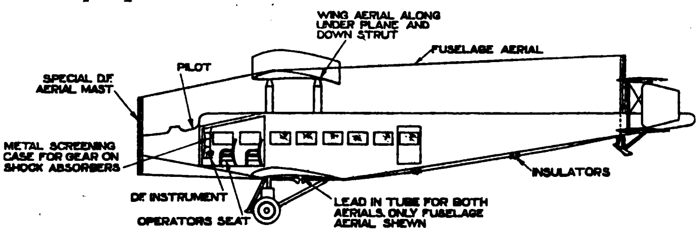


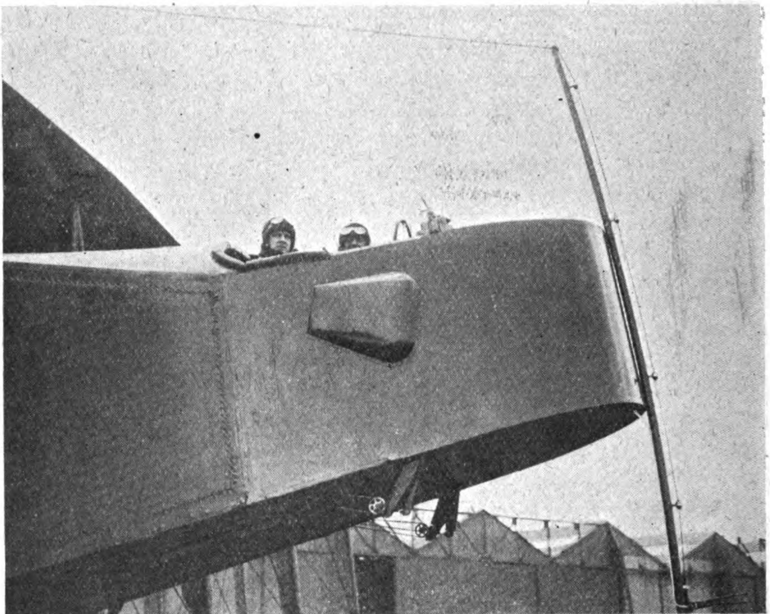
Fig. 238. *M.-B.-T. Fore and Aft Aerial Supported on Masts* (*see Fig.* 239).

In single-engine machines the fore and aft aerial may be split into two and brought down on either side of the engine, as shown in Fig. 240. It must never be brought down on one side only, or the fore and aft aerial will be thus coupled to the wing aerial.

The M.-B.-T. Double Turn Fore and Aft Loop. When it is found quite impossible to rig a single turn loop of adequate size, a double turn may be employed. In the case of the single engine machine, this forms a convenient way of avoiding the coupling between the fore and aft, and the wing aerials, as the two turns may be brought down on opposite sides of the engine cowling.

PRECAUTIONS AGAINST MAGNETO INTERFERENCE.

Magneto interference, in aircraft, is not peculiar to D.F. working but owing to the use of the frame aerial in place of the trailing aerial, the problem of its elimination becomes more difficult.



Sport & General

Fig. 239. View of Fore Mast used in Special Cases to support M-B-T Fore and Aft Loop.

It has been demonstrated, beyond all doubt, that the interference in the receiver is due to the short wave radiated from the engine ignition system, as already mentioned on page 299. Some attempts were made to prevent these short waves from affecting the receiver by putting " tuned stopper " circuits in series with the leads to the amplifier, as shown in Fig. 241 and at the same time enclosing all the receiving apparatus in metal screens. This provided a partial solution but the results were by no means perfect. (79).

The final solution was found to be the complete screening of the whole of the ignition system, including the magneto, the leads to the sparking plugs, the plugs themselves, and the controls from the magneto to the cockpit.

A Rolls-Royce Eagle engine, with screened ignition, is shown in Fig. 242, installed in a Short flying boat. A metal screen completely encloses the magneto, and the wiring is covered with copper braid. If the screening is stopped at the point where the high-tension lead is connected to the plug, the radiation from the plug and short length of exposed lead is enough to prevent wireless reception. Fig. 243 shows a specially screened plug developed by the Marconi Company and the Robinhood Engineering Works, which has proved an efficient remedy for the trouble. The engine in Fig. 242 is fitted with these plugs.

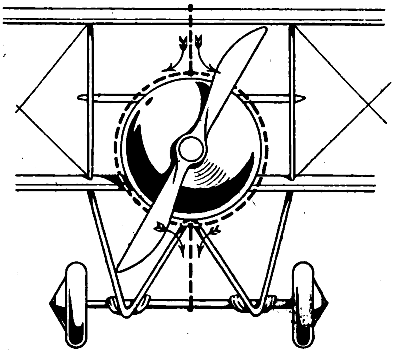


Fig. 240. *Method of running Fore and Aft M-B-T Loop to clear Engine on Single Engine Machine.*

The cylinder wall forms the return path from the plug to the engine casing, and the interference due to this varies considerably with the type of cylinder construction. Steel and iron cylinders offer the greatest impedance to the high-frequency oscillatory currents, and are the worst offenders; but an improvement is effected by fitting a copper bonding between the body of the plug and the engine framing. Less trouble is noticed in the case of aluminium cylinders having a steel liner; a copper water-jacket also acts as an efficient low-impedance path.

High compression engines require a higher sparking potential and produce greater interference and a gradual increase in the interference has been noted from an engine, as the cylinders and piston heads became carbonised with corresponding increase in compression.

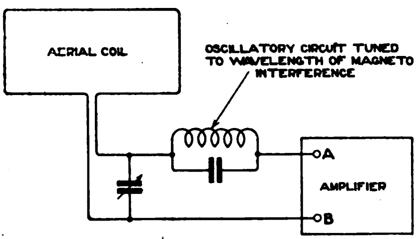


Fig.* 241. "*Tuned Stopper*" *Circuit for Elimination of Magneto Interference.

It may happen in certain cases that very little screening is necessary. Rotary engines have only very short lengths of ignition wiring, which is

kept close to the cylinder wall in every case, and the interference from such a system is not so troublesome as from a stationary engine, which frequently has duplicate ignition controlled from the cockpit and involving great lengths of wiring. Again, the metal cowling of the majority of stationary engines forms, itself, an efficient screen, provided that it is made completely to surround the engine.

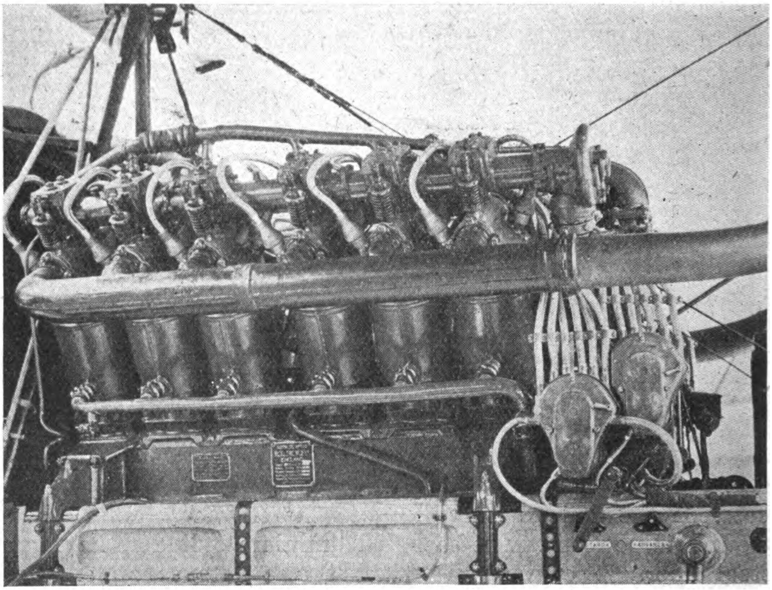


Fig. 242. *Rolls-Royce Engine fitted with Screened Ignition and Screened Sparking Plugs*

Wireless Telegraph Generator. The high-tension generator for the wireless transmitter is usually a totally enclosed machine, and the leads are metallic braided, so that interference from this source need not be anticipated except owing to a fault in the wireless telegraph circuits.

Temporary or Additional Screening Measures. When it is necessary to screen an ignition system which has not been designed with a view to the possible requirements of the wireless equipment, the best method is to enclose the wiring in copper gauze, put on in strips, the seams soldered in as many places as possible and well bonded to the earth trunk. If the ignition wiring is taken through aluminium tubes at any point, this will provide efficient screening, but the tubing

must be bonded by copper gauze at each end to the main earth. In the case of large or multi-engined machines in which the wiring is carried to the engines through stream-lined control spars, the spars should be covered with gauze and the joints soldered, the whole covering being well secured with binding wire.

Electric lighting leads which pass near to the ignition system will also cause trouble, and must be treated in a similar manner to the ignition.

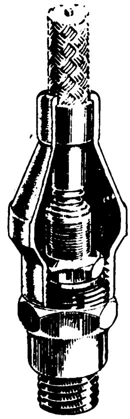


Fig. 243. *Screened Sparking Plug.*

An important factor throughout all aircraft work is that any devices which, in the opinion of pilots or inspectors, detract in any way from the safety of the machine or from the accessibility of any parts requiring examination, will not be tolerated, and co-operation with the proper authorities is very necessary when devising screening methods and installing the apparatus.

Effects of Vibration. The constant vibration during flight and also the landing shocks have a destructive effect on all wireless apparatus, and as much as possible of the equipment should always be supported on shock absorbers. To prevent the chance of the internal connections of amplifiers and similar instruments coming adrift, the wires should always have pinched or screwed joints, in addition to being soldered. A loose connection or a loose electrode in a valve will produce a noise in the telephones which may be as serious as, and may even be mistaken for, magneto noise.

CHAPTER 10.

FAULT CLEARING AND MAINTENANCE.

In this chapter will be found, roughly classified, some of the more common faults which may arise in D.F. reception, together with the symptoms by which the probable cause of the failure may be recognised. In cases where the remedy is not obvious, suggestions are made as to the methods to be adopted to clear the fault, or cross references are given to more detailed accounts of the cause.

Symptoms of failure may be placed under the following headings :—

Signal strength zero, weak or varying.
Noises in telephone receivers.
Bearings incorrect.
Figure eight minima indefinite.
More than two minima exist.
Heart-shape minimum indefinite.
Reversed sense. (Page 45.)

No Signals.

(*a*) Broken or " dry " connection at any point in the circuit from the aerial to the telephone receivers.—Try potentiometer contact, connections of variable condensers, telephone leads, etc.
(*b*) Switch open.—Try aerial disconnecting switches, valve filament battery switch, wave range switches.
(*c*) Aerial carried away.
(*d*) Earthing relay has contacts short-circuited.
(*e*) Lightning arrester short-circuited.
(*f*) Valve electrodes in contact.
(*g*) Valve filament burnt out.
(*h*) Valve not making contact in holder.
(*j*) Jammed by strong continuous wave station, causing saturation of rectifier valve.
(*k*) Circuit oscillating persistently owing to soft valve.
(*l*) Failure of amplifier due to disconnection in intervalve transformer or breakdown of insulation.

The symptoms of both (*j*) and (*k*) may at times be the same, namely, a breathing sound with complete absence of

signals ; but when this is caused by a jamming station, normal conditions should be restored on rotating the frame so as to cut out these signals.

If the fault be traced to the amplifier and an examination of the connections does not yield any result, the following two tests should be applied :—

Test for Insulation of H.F. Cascade Amplifier. If the amplifier be of the type illustrated in Fig. 191 or similar in design, it will be found that in every case the grid clips of one valve and the anode clips of the next have a small condenser connected across them, which is therefore in parallel with the condenser formed by the capacity between the two windings of the intervalve transformer. When the filament battery switch is closed, all these small condensers are in parallel and an insulation test made between any pair of clips gives the insulation of all the intervalve transformers and also of the condensers. A simple method of making the test is to connect a pair of telephone receivers in series with a 24-volt battery and, having removed the valves, join one lead to a grid clip and tap the other lead several times on one of the anode clips. When the first contact is made a click will be heard in the telephones, which is caused by the charging current of the small condensers mentioned above. Subsequent contacts ought to produce only very weak clicks, owing to the fact that the condensers have been charged to the potential of the battery used for the test by the first contact. If loud clicks are heard at each contact it shows that the condenser charge is leaking away instantaneously, owing to faulty insulation, and by disconnecting the intervalve transformers and condensers one at a time the faulty unit can be found.

Another method of making the tests is to keep the testing battery and telephones connected for a moment and then note whether there is a click on *breaking* the circuit again. This would be caused by the interruption of a steady current flowing through the faulty insulation.

Test for Continuity of H.F. Cascade Amplifier. The continuity of each winding of the intervalve transformers may be tested separately, since it will be seen (Fig. 191) that one end of each anode winding is connected to the positive terminal of the anode battery. Using a 24-volt battery and telephones as before, if one lead be connected to the terminal to which the positive battery lead is normally joined, while the

other lead be tapped successively on all the anode clips, a loud click should be heard in each case. Absence of this click or a continuous noise indicates a broken winding. The grid winding may be tested in a similar way by making contact between the negative filament battery terminal and successive grid clips. It should be ascertained that the circuit is not open owing to the battery switch being left open.

Signals Fall Off in Strength Gradually.

(*a*) Faulty connections anywhere in the circuits.
(*b*) Anode or filament batteries need charging.
(*c*) Night effect. (See pages 179 and 182.)

Noises in the Telephones. These are usually "sizzling" or "frying" noises, and are more or less continuous.

(*a*) Bad connection of filament clip with valve.
(*b*) Faulty internal filament connection in valve.
(*c*) Bad insulation of anode battery.
(*d*) Bad contacts in anode or filament batteries, due to loose terminals or corrosion.
(*e*) Intermittent break in intervalve transformer.
(*f*) Bad contact on potentiometer or filament rheostat.
(*g*) "Fizzly" atmospheric caused by rain from charged clouds falling on aerial and discharging to earth through the receiving apparatus.
(*h*) Electrical interference from power supply or, especially in aircraft, from magneto interference (page 312.)

Bearings of All Stations appear in Same Direction. In the case of the M-B-T system, the direction generally coincides with one of the frame aerials. The fault is due, in almost every case, to a disconnection or short circuit in the other aerial circuit, owing to—

(*a*) Aerial switch open.
(*b*) Faulty lead-in (and damaged cable in a ship installation).
(*c*) Faulty aerial tuning condenser (if fitted).
(*d*) Leads from one aerial, or terminals on aerial switch or radiogoniometer, accidentally shorted by wire or tools.

Figure Eight Minima not Opposite on Scale.

(*a*) Vertical or Direct. (Pages 30 and 237).
(*b*) Un-balance of Aerials. (Pages 268 and 279).

No Directional Reception. Signals are received with almost equal intensity at all points of the scale.

(*a*) Break in search coil circuit, in which case the signals are received owing to the capacity coupling of the radiogoniometer, or alternatively by vertical aerial coupling coil (or " sense " winding on the shielded transformer, Fig. 179) in the case of the heart-shape circuit. (Page 64.)

(*b*) Break in the aerial or search coil circuit and a large degree of "direct" reception present. (Pages 31 and 237.)

Rotation of Bearings, *i.e.*, all too high or too low.

(*a*) Mistake in the calculation or estimation of the direction of North. (Pages 207 and 335.)

(*b*) Pointer of frame or search coil, moved on its spindle. (See pages 205 and 256.)

(*c*) Wrong aerial connections. (See page 320.)

Bearings Incorrect in certain Directions only.

(*a*) Night effect. (Page 164.)

(*b*) Coupling error of radiogoniometer, in which case bearings will be correct in eight directions, coinciding with the planes of the two sets of field coils and the planes midway between these—that is to say, every 45°. (See page 58.)

(*c*) All bearings have drift towards a certain direction, due to underground cables, telegraph wires, an adjacent tuned transmitting or receiving aerial, etc. (See pages 204 and 259.)

(*d*) Local screening, causing errors of several degrees in one or two directions only, due to trees, buildings, etc. (See page 203.)

(*e*) Coast refraction. Station situated so that path of incoming waves cross coastline at oblique angle, giving errors up to 5°. (See page 161.)

Bearings Incorrect on Certain Wavelengths only.

(*a*) Adjacent transmitting or receiving aerial tuned to D.F. wavelength. (Page 203.)

(*b*) Natural wavelength of leading-in cables, aerials and field coils coincides with D.F. wavelength. (Page 279.)

(*c*) Night effect. (Page 191.)

More than Two Minima with Figure Eight Circuit.

(*a*) Local oscillator coupled with radiogoniometer or aerial. This will only occur, of course, in reception from a C.W. station. (See page 87.)

Indefinite Minima (Figure Eight Diagram of Reception).

(*a*) Night effect. (Pages 164 and 192.)

(*b*) High resistance contact in the circuit of the search coil or shielded transformer. This will allow of a certain amount of directional reception, but also weak signals in any direction, owing to the capacity coupling between the windings of the radiogoniometer or the shielded transformer.

(*c*) Shield disconnected in transformer. If the vertical is very great, and also out of phase with the frame reception, the diagram of reception will be as shown in Fig. 21.

(*d*) High resistance in either or both aerial circuits. (Pages 55 and 222.)

(*e*) Earth connection (when fitted) of mid-point of field coils bad or disconnected. Same effect as (*c*). (See also pages 268 and 279.)

(*f*) Bad insulation in aerial circuit, particularly in the lower limbs or lead-in. (See pages 221 and 279.)

(*g*) Fluff between the vanes of aerial tuning condensers introduces losses in the aerial circuits equivalent to high resistance.

(*h*) Telegraphist resting hand on terminals when taking bearing.

(*i*) Mutual inductance or capacity between aerials. (Page 55.)

Indefinite Minimum, Heart-shape Circuit. (See page 246.)

Heart-shape Balance obtained with very low and Variable Value of Phasing Resistance.

Connections to earth lead faulty or station earth in bad condition. This fault has, on some occasions, made its appearance during a long spell of dry weather, when the earthplates were making very indifferent contact.

FAULTS DUE TO WRONG CONNECTIONS OF M-B-T AERIALS TO RADIOGONIOMETER.

(1) Stations the true bearings of which are a certain number of degrees EAST of North appear WEST of North by an equal amount.

Reversal of leads from one aerial to radiogoniometer, which may be remedied by reversing the connections of either aerial. (See page 321.)

(2) All Bearings are 90° Wrong.

(*a*) See page 319, " Rotation of Bearings " (*a*) and (*b*).

(*b*) Interchange aerials and reverse one of them. (That is to say, the leads connected to the N.S.E. and W. terminals of the radiogoniometer are transferred respectively to the E.W.S. and N. terminals, or to the W.E.N. and S. terminals.)

(3) Bearings are Correct only on Subtracting from 90° (or from 180° when the Observed Bearing is greater than 90°).

Interchange aerials. (That is to say, the leads connected to the N.S.E. and W. terminals of the radiogoniometer are transferred respectively to the E.W.N. and S. terminals.)

In the case of a ship installation, for N.S.E. and W., read :—Fore, Aft, Starboard and Port.

It may be noted that the remedies for any given errors as stated above are dependent on two factors, namely :—

(1) The direction of True North relative to the plane of the frame aerials.

(2) The direction of the 0°-180° line of the scale of the radiogoniometer, relative to the planes of the field coils.

Regarding the first of these, it has been assumed throughout the book that the M.-B.-T. aerials will always be laid out North-South and East-West (or in the case of a ship installation, Fore-Aft and Starboard-Port), and so it is not necessary to consider other types of layout. Referring to the second factor, the radiogoniometers mentioned in the foregoing chapters, whilst not identical in design, are so far similar that the same errors are produced by wrong connections and the remedies given above therefore apply to all of them.

Practical Example of Errors in Laying Out and Connecting Up M-B-T Aerial. To show the confusion which may arise from lack of care in laying out the aerial system and connecting the aerial leads to the apparatus, we may instance an actual case. A temporary station had to be erected very hurriedly, and in laying out the aerials an estimate was made of the direction of North, since no compass or map was available and the sky was completely overcast.

After connecting up the radiogoniometer, bearings were taken on a number of known stations, the true bearings of which were obtained from a gnomonic chart, and the results are tabulated below :—

Station.	Observed Bearing.	True Bearing.	Error.
Eiffel Tower	$183\frac{1}{2}°$	$145°$	$+ 38\frac{1}{2}°$
Cullercoats	$222\frac{1}{2}°$	$106\frac{1}{2}°$	$+ 16°$
Malin Head	$245\frac{1}{2}°$	$263\frac{1}{2}°$	$- 18°$
Glasgow (temporary station)..	$305°$	$24°$	$- 79°$
Seaforth	$171\frac{1}{2}°$	$158°$	$+ 13\frac{1}{2}°$
Land's End	$141\frac{1}{2}°$	$188°$	$- 46\frac{1}{2}°$
Fishguard	$144°$	$185°$	$- 41°$

At first sight there appeared to be no consistency about the errors, but on applying the various remedies for cross connection of aerial leads a solution was found. On the assumption of an *East and West reversal* of all bearings the corrected bearings have been tabulated again. Thus the observed bearing of Eiffel Tower was $183\frac{1}{2}°$ East of North ; if this be taken to be his bearing *West* of North, we get a value for the true bearing of $360° - 183\frac{1}{2}° = 176\frac{1}{2}°$, and so on.

Station.	Observed Bearing.	Bearing Assuming an East and West Reversal.	True Bearing.	Error.
Eiffel Tower ..	$183\frac{1}{2}°$	$176\frac{1}{2}°$	$145°$	$+31°$
Cullercoats ..	$222\frac{1}{2}°$	$137\frac{1}{2}°$	$106\frac{1}{2}°$	$+31°$
Malin Head ..	$245\frac{1}{2}°$	$294\frac{1}{2}°$	$263\frac{1}{2}°$	$+31°$
Glasgow	$305°$	$55°$	$24°$	$+31°$
Seaforth	$171\frac{1}{2}°$	$188\frac{1}{2}°$	$158°$	$+30\frac{1}{2}°$
Land's End ..	$141\frac{1}{2}°$	$218\frac{1}{2}°$	$188°$	$+30\frac{1}{2}°$
Fishguard ..	$144°$	$216°$	$185°$	$+31°$

A constant error of about 31° results from this, and it was found later to be due to incorrect guessing of the direction of North, and was corrected by rotating the pointer of the radiogoniometer through 31° on its spindle. The other fault, namely, the East and West reversal, came about through reversing the aerial leads to one set of field coils, and after connecting them properly the installation was perfectly satisfactory.

CHAPTER 11.

NOTES ON FIELD AND NAUTICAL ASTRONOMY.

In the ensuing pages are described the solutions of a number of the more common problems of field and nautical astronomy, a knowledge of which may, at any time, prove of use to engineers engaged in the erection of direction-finding stations. The notes are by no means exhaustive, and more advanced books on the subject should be consulted for further details. A certain amount of familiarity with the use of the theodolite and similar instruments is assumed.

Solar Observations. The methods to be described for finding latitude, longitude, true North from azimuth of heavenly body, etc., deal only with solar observations, space not allowing of a treatment of the more general use of observations on stars and planets.

The solution, from first principles, of many of the problems which are met with, requires a knowledge of elementary spherical trigonometry, but they have been set out in this chapter in such a way that they entail only a familiarity with the use of Inman's Nautical Tables, the Abridged Nautical Almanac and Burdwood's Azimuth Tables.

A brief introduction to the subject of nautical astronomy and an explanation of the terms used will enable the steps of subsequent calculations to be followed with greater ease and reduce the chance of making slips when reproducing them.

Position of Heavenly Bodies. At the beginning of Chapter 4 it was seen that the method of locating a point on the surface of the earth is by means of latitude and longitude, and a very similar process is adopted in regard to the heavenly bodies. We know that actually the earth rotates about its axis once in twenty-four hours, and that, furthermore, it takes an elliptical path round the sun once in a year. In addition to these motions the sun and the whole solar universe have a definite motion, but for astronomical purposes it is found more simple to suppose the earth to be still and all the remaining heavenly bodies moving, their relative positions being designated in the following manner.

Imagine that the earth is at the centre of an infinitely large sphere, and that on the interior of the sphere are projected from the earth's centre all the meridians of longitude and parallels of latitude. If, now, an observer on the earth concentrates his gaze on the inner surface of this sphere with its imaginary lines of latitude and longitude, all the heavenly bodies will appear to be moving relatively to it, and at any instant their position could be stated in latitude and longitude, just as in the case of a point on the earth. This infinite sphere is called the **celestial concave,** which is illustrated diagrammatically in Fig. 244, and the **celestial meridians** and **celestial equator** are seen to be projections of the corresponding lines on the earth.

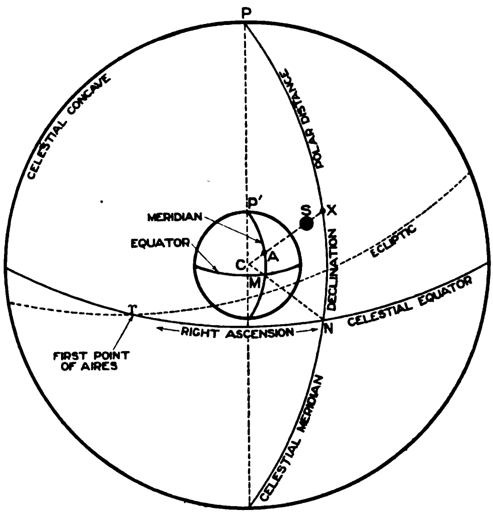


Fig. 244. *True Position and Geographical Position of Heavenly Bodies.*

The projections on the celestial concave and on the earth respectively of any heavenly body are called the **true position** and the **geographical position** of the body. Thus, in Fig. 244, S represents the sun in space, X being its true position and A its geographical position.

Declination. Latitude, when referred to the celestial concave, is called declination. In Fig. 244 the arc AM is the latitude of the geographical position of the sun S and the arc XN on the celestial concave is the declination. In the Nautical Almanac will be found tabulated the declination for

any time of day throughout the day and year, of the sun, moon and principal planets and fixed stars.

Polar Distance. The co-latitude P′A of the point A, when referred to the celestial concave, becomes the polar distance PX.

Right Ascension. The measurement of celestial longitude is rather less straightforward than on the earth, where the prime meridian is chosen, purely arbitrarily, as the one which passes through Greenwich. In Fig. 245 is illustrated the path of the earth round the sun, and it will be noted that the axis of the earth is tilted relative to the plane of the earth's path or **ecliptic,** so that the plane of the ecliptic and that of the equator make an angle with one another of 23° 27′. Since we are assuming in Fig. 244 that the earth is stationary, the sun will appear to move across the celestial concave in an oblique path, which makes an angle of 23° 27′ with the celestial equator and will cross the latter at two points. One of these points is named "The **first point of Aries,**" signified by the character ♈ and is taken as the point of reference for celestial longitude. The arc of the celestial equator ♈N of any heavenly body (in this case the sun) is the Right Ascension, and is measured in an easterly direction from 0° to 360°, or from 0 to 24 hours. The R.A. of the moon, planets and principal fixed stars is tabulated in the Nautical Almanac.

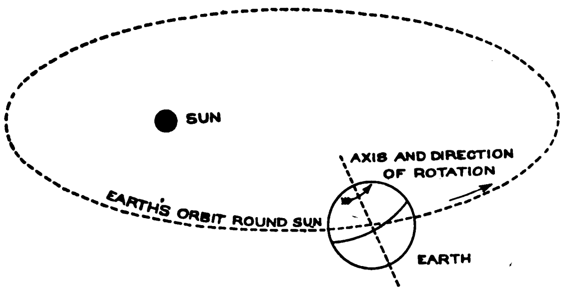


Fig. 245. Movement of the Earth round the Sun.

Sidereal Time. The earth rotates on its axis at a constant rate, and the time elapsing between successive passages of a star across any given meridian is a Sidereal Day. The sidereal day is said to start from the time of passage of the first point of Aries across the meridian, and sidereal time is thus seen to coincide with Right Ascension. A clock can be regulated to keep sidereal time.

Apparent Time. Owing to the apparent movement of the sun in the ecliptic, the time elapsing between successive passages of the sun across any meridian is not a constant quantity, and is called a Solar Day. A clock cannot be regulated to keep Solar Time, which is the time shown by a sundial and is known as Apparent Time.

Mean Time. For the sake of convenience a mean solar day is taken as our standard, which is equal to the time which would result from an imaginary mean sun which moved at a uniform rate round the celestial equator instead of the ecliptic. The Right Ascension of this Mean Sun (R.A.M.S.) is measured eastward from the first point of Aries from 0° to 360°, or 0 to 24 hours, and is tabulated in the Nautical Almanac. The mean solar day begins when the mean sun crosses the meridian, and a clock regulated to keep this time is said to show Mean Time.

Greenwich Mean Time (G.M.T.) is reckoned from Greenwich noon, which is the instant of passage of the mean sun across the meridian of Greenwich. The **Civil Day,** for the sake of convenience, is reckoned from midnight instead of noon.*

Equation of Time. The difference, at any instant, between mean and apparent time is known as the Equation of Time, and is tabulated in the Nautical Almanac, where it should be carefully noted that when the Eq.T. is "+ ve," it indicates that it must be *added* to apparent time to give mean time, and *vice versa*.

Zenith Distance. In Fig. 246, S again represents the sun and A and X its geographical and true positions respectively. Suppose B to be any other point on the earth, with corresponding position Z on the celestial concave. Then Z is the zenith of B and the arc ZX is the zenith distance between Z and X (usually expressed as the angle ZCX). The (Angular) zenith distance multiplied by the radius of the earth is clearly the great circle distance between A and B.

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*The following notice appears on the cover of the current Nautical Almanac: "In both the abridged and complete Nautical Almanac the times styled G.M.T. are at present reckoned from noon, corresponding to 12 hours (Civil Time); but from the year 1925 inclusive and thenceforward the times styled G.M.T. in these publications will be given commencing at midnight, to conform with Civil Time; the term "Greenwich Mean Time" will then be considered to be the Standard Time of the meridan of Greenwich, commencing at midnight and reckoned throughout the 24 hours."

Azimuth. In Chapter 4 we saw that the angle ABP′ was the true bearing, or azimuth, of A at the place B. Similarly, when referred to the celestial concave, XZP is the azimuth of X.

Hour Angle. H, the angular distance westwards of the celestial meridian of the heavenly body S from the celestial meridian of the place B, is the Hour Angle. In the case of the sun, the hour angle is a measure of the apparent time.

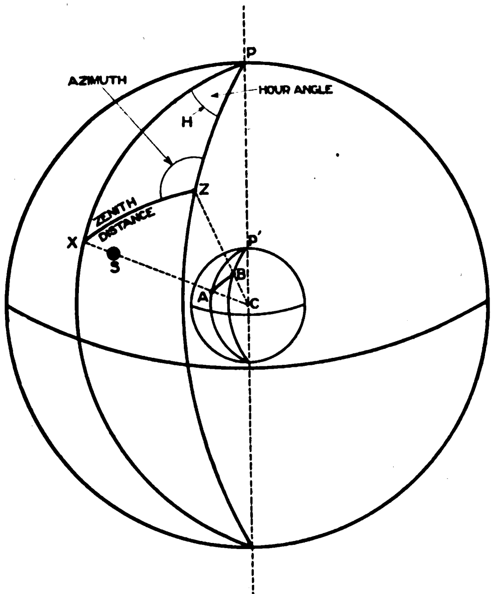

Fig. 246. *Azimuth, Zenith Distance and Hour Angle.*

Hour Angle and Difference of Longitude. Knowing the hour angle of the sun at any given place, the difference of longitude between the geographical positions of the sun and the place may be found at once by converting the hour angle to degrees. This may be taken out of Inman's Tables, or found very simply from the following relations :—

Time.		Arc.
24 hours	.. .. ..	360 degrees.
1 hour	.. .. ..	15 degrees.
4 minutes	.. .. ..	1 degree.
1 minute	.. .. ..	15 minutes.
4 seconds	.. .. ..	1 minute.
1 second	.. .. ..	15 seconds.

Timing of Observations. In practically all astronomical work the question of time is involved, and preparations should be made for the accurate measurement of the instant at which observations are made. For this purpose any good watch is satisfactory, provided that means are available for checking the watch. The only really reliable method of making this check is by means of a wireless time signal, or some other reliable sort of time signal which is operated from an observatory. In the case of wireless signals, arrangements can usually be made for their reception, even though the permanent station buildings are not available for the purpose. The correction should be made to the nearest half-second, and no more time should elapse than is necessary between the checking of the watch and the making of the observations.

When observations are being made on board ship, the ship's chronometers will be available for obtaining the time without the necessity for recourse to any other time signal.

Problem 1.—To Calculate the Time of Apparent Noon at Place in Terms of G.M.T. or Local Standard Time. Suppose that a D.F. station has been erected on Robben Island (Table Bay), and that it is desired to find the time of apparent noon at that place in G.M.T. or in South African Union Time, which is two hours *fast* of Greenwich Mean Time. The work may be set out as follows :—

ROBBEN ISLAND. Date, February 15th, 1919.

Longitude .. 18° 21′ 0″ E.

South African Union time, 2 hours fast of G.M.T.

A.T.P. ..	24 hr.	00 m.	00 s.	Feb. 14th ..	(1)
Long. E. ..	1	13	24	.. ..	(2)
G.A.T. & G.D.	22	46	36	Feb. 14th ..	(3)
Eq. T. ..	+	14	19½	.. ..	(4)
G.M.T. ..	23	00	55½	.. ..	(5)
	2	00	00	.. ..	(6)
	25	00	55½	.. ..	(7)
	24	00	00	.. ..	(8)
S. African Time	1	00	55½	.. ..	(9)

From this we see that if a watch which had been set to read South African Union time, and which had been corrected by means of the wireless signal which is transmitted daily by the Royal Cape Observatory from the Slangkop wireless station had been used, say, for the purpose of timing a meridian altitude of the sun, then the observation would

have to be made when the watch read 1 hr. 0 min. $55\frac{1}{2}$ sec. p.m. (civil time). The corresponding G.M.T. would be 11 hr. 0m. $55\frac{1}{2}$ sec. a.m. (civil time).

Explanatory Notes on the above Example.

(1) Write down the time which it is required to convert to Greenwich or local time—in this case "noon on Feb. 15th, 1919"—which is 24 hr. 0 m. 0 s., Feb. 14th in astronomical time. (See footnote, page 326.)

(2) Write down the longitude of the place, *converted to time.* (See method of converting hour angle from time to degrees, on page 327.)

(3) For longitude West, add (1) and (2); for longitude East subtract (2) from (1), giving Greenwich apparent time and hence Greenwich date. Had the longitude of the place been West, this time would be greater than 24 hours and Greenwich date would have been Feb. 15th instead of Feb. 14th, since the astronomical day begins at noon on the civil day of the same date, and this would affect the value of the equation of time as found in the tables.

(4) Take from the Nautical Almanac the equation of time for the Greenwich date and apparent time.

(5) Add or subtract the Eq. T. according to sign, giving the Greenwich mean time.

(6) Write down the difference between Greenwich and local time.

(7) Add (6) and (7) if local time fast of G.M.T.; subtract if slow.

(8) If (8) be greater than 24 hours, subtract 24 hours, giving :—

(9) Local standard time corresponding to time of apparent noon, adding 12 hours to convert to civil time. In this case it is only necessary to add "p.m." thereby adding 12 hours.

Problem II. To find the Time of Apparent Noon at Place, and hence the Longitude, by Observations of Equal Altitudes of the Sun. In making its passage across the sky the sun appears to take a straight path or a curved one, according to whether it passes through the zenith of the observer or not. In any case, the instant of maximum altitude is that corresponding to the time at which the sun

crosses the meridian of the observer, and is the time of apparent noon at the place.

The method of finding the time of apparent noon by means of a theodolite consists in noting any two times before and after noon respectively, when the altitude of the sun is the same, the mean of these times being that of "meridian passage."

In those parts of the world and in seasons of the year when the sun is almost overhead at noon, the method is easy to apply, as the altitude of the sun is changing rapidly and the time corresponding to a given altitude can be noted with a fair degree of accuracy. When the altitude is low at noon, however, the sun follows a curved path, as shown in Fig. 247, and owing to the comparative flatness of this curve it becomes necessary to take the readings at much greater intervals before and after noon, in order to obtain accurate results, and a total interval between the first and second reading of several hours may be advisable in extreme cases.

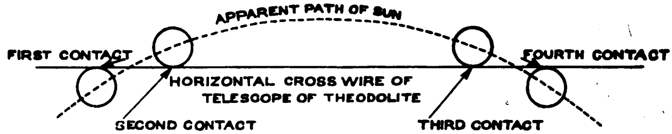

Fig. 247. Contacts of Sun's Image with Cross Wire of Theodolite.

In practically all cases the approximate position of the place will be known to within a few miles, and hence the time of apparent noon can be calculated to within a few minutes. This is of use, as having decided upon the time at which the first observation is to be taken, the approximate time of the second can be calculated and will prevent waste of time in standing by the theodolite all the time.

The theodolite having been carefully levelled, the telescope is fitted with the solar eyepiece, and is so adjusted that the sun is visible in the field of the instrument and is approaching but not in contact with the horizontal cross wire. The vertical movement of the telescope is now locked in this position, the horizontal movement being left free.

At the instant of contact of the sun with the horizontal cross wire the observer gives a signal, and a second observer notes the time. The sun is now allowed to rise to its zenith and at the instant of leaving the horizontal cross wire again on its downward path, the time is again noted. (If the interval

between the two readings is sufficiently great, the times of all four contacts as shown in Fig. 247 may be taken; the mean of the first and fourth, and of the second and third, should of course be the same.)

The chief point to be noted is that, once the first reading has been taken, great care must be taken not to alter the vertical setting of the instrument.

Example. Suppose that in estimated longitude 88° E. on March 16th, 1921, it is desired to find the time of apparent noon and hence the true longitude by means of the times of equal altitudes of the sun, and that the following data have been obtained. By means of a time signal the error of the watch has been found to be 5 hr. 54 m. 50 s. *fast* on G.M.T. and the times of the two contacts (that is, the first and fourth, in Fig. 247) were 10 h. 53 m. 45 s. a.m. and 1 hr. 28 m. 25 s. p.m. respectively by the watch. The work may be set out as follows :—

Date, March 16th, 1921.

Estimated longitude ..	88° East.				
Error of watch ..	5 h.	54 m.	50 s.	fast on G.M.T.	
Time of apparent noon	6	16	56	a.m. G.M.T.	(1)
Watch fast ..	5	54	50	.. ..	(2)
Apparent noon by watch	12	11	46	p.m. ..	(3)

Owing to the sun being rather low, it was decided to take the altitudes approximately two-and-a-half hours apart :—

Time of first contact	10 h.	53 m.	45 s.	a.m. ..	(4)
Time of last contact	13	28	25	p.m. ..	(5)
Time of apparent noon	12	11	5	.. ..	(6)
	00	11	5	Mar. 16th ..	(7)
Watch fast ..	5	54	50	.. ..	(8)
G.M.T. & G.D. ..	18	16	15	Mar. 15th ..	(9)
Eq. T.		− 8	56	.. ..	(10)
G.A.T.	18	7	19	.. ..	(11)
H.A.	271°	49′	45″	.. ..	(12)
Long. E.	88°	10′	15′	.. ..	(13)

Explanatory Notes on above Example.

(1) Find G.M.T. corresponding to apparent noon in estimated longitude, as described in Problem I.

(2) Write down the correction for the watch.

(3) Subtract correction if watch fast, add if slow, giving time by watch of apparent noon (approx.).

(4) and (5) Write down times by watch of first and last contact.

(6) Take mean of (4) and (5).

(7) Write down (6) in astronomical time, remembering that the astronomical day begins at noon on the civil day of the same date. (See footnote, page 326).

(8) Write down the correction for the watch.

(9) Subtract correction if fast, add if slow, giving Greenwich mean time and date.

(10) From the Nautical Almanac find the equation of time for the Greenwich time and date, and write it down under the Greenwich time *with sign reversed,* since we are converting G.M.T. to G.A.T. (See definition page 326.)

(11) Add or subtract the Eq. T. according to reversed sign, giving G.A.T. corresponding to apparent noon at place.

(12) Convert G.A.T. to angular measure, giving hour angle or West longitude. (Page 327).

(13) Subtract (12) from 360°, giving longitude *East* of Greenwich.

Problem III.—To Find the Meridian Altitude of the Sun by Observation, and hence the Latitude. When the sun is in the meridian of the observer, its altitude is a simple function of the latitude of the observer and the sun's declination. Suppose that in Fig. 248 the declination is zero—that is to say, the sun is in the plane of the equator, and that an observer at A finds the altitude to be 50°. In this case the angle POA will also be 50°, and hence the latitude is 90°—

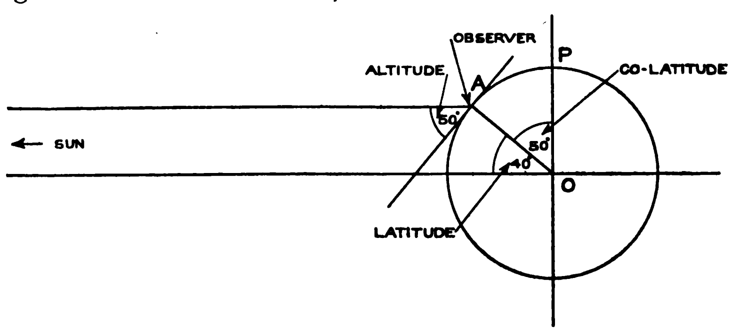

Fig. 248. *Latitude as a function of Sun's Altitude.*

50°=40°. The path from the observer to the sun is shown as being parallel to the plane of the equator on the assumption that the sun is at an infinite distance.

In Fig. 249 the sun is in declination 20° North, and an observer at A now finds the altitude at apparent noon to be 70°. The angle POA is now equal to 70°−20°=50°, and again the latitude is 40°.

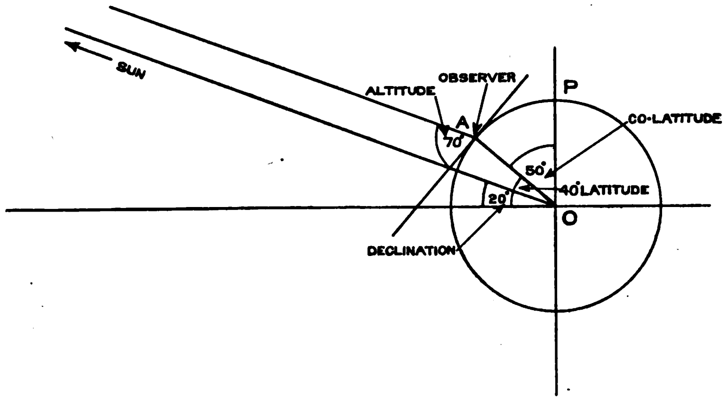

Fig. 249. *Latitude as a function of Sun's Altitude and Declination.*

The altitude of the sun is, in fact, the co-latitude of the observer plus or minus the declination, according to whether it is of contrary or same name. (That is to say, according to whether one is North and the other South, or whether both are North or both South.) A slight error is introduced by the assumption that the sun is at an infinite distance and a correction should be introduced for **Parallax**, the value of which varies from 0 to 8·8 seconds of arc, according to the altitude.

In order to find the instant of maximum altitude, using a theodolite, the simplest method is probably as follows :—

Proceeding exactly as described in the previous problem, the image of the sun is obtained in the telescope shortly before the time of apparent noon at the place, the telescope being adjusted so that the upper limb of the sun is just in contact with the horizontal cross wire. Now, as the sun continues to rise towards its zenith, the telescope is gradually moved by means of the screw adjustment, keeping the cross wire always just in contact with the sun's image, the lateral movement being allowed for by moving the telescope in a horizontal plane. The altitude of the sun will increase more and more slowly towards the maximum, and finally, after a period of

apparent rest, will begin to decrease again ; but the telescope must be left in the position of maximum altitude. The angle registered on the vertical scale will be the altitude of the upper limb of the sun at apparent noon, and if we subtract the "semi-diameter" of the sun, apply a correction for parallax and add or subtract the declination, we get the co-latitude of the place.

The method is only applicable when the sun is fairly low at noon ; as it reaches the zenith of the observer the accurate measurement of the altitude by the above means becomes impossible.

Example. Suppose that on April 24th, 1921, in estimated longitude 88° East and latitude 43° North, it is desired to find the meridian altitude of the sun, and hence the true latitude, using a theodolite. The work may be set out as follows :—

Date, April 24th, 1921.

Estimated longitude .. .. .. 88° E.
Estimated latitude .. .. .. 43° N.
G.M.T. and G.D. of
apparent noon 18 h. 6 m. 12 s. April 23rd (1)

Arrangements were therefore made to start observations a few minutes before this time, and the maximum altitude was found to be 59° 47′ 47″.

Uncorrected observation	59°	47′	47″	..	..	(2)
Semi-diameter ..		15	56	..	..	(3)
Apparent altitude	59	31	51	..	..	(4)
Parallax			5	..	..	(5)
Altitude	59	31	56	..	..	(6)
Declination N. ..	12	41	20	..	..	(7)
Co-lat.	46	56	36	..	..	(8)
Latitude	43	03	24	..	..	(9)

Explanatory Notes on Above Example.

Since in this method of obtaining latitude the exact time of the observations is not required, there is no need to make accurate check of the watch used, and the only important point is that the observations must be commenced before apparent noon.

(1) Find the G.M.T. and G.D. of apparent noon in the estimated longitude, as described on page 328, Problem I, and hence the approximate time at which to start the observations.

(2) Write down the observed altitude of the upper limb of the sun.
(3) From the Nautical Almanac obtain the semi-diameter of the sun for the Greenwich date.
(4) Subtract the semi-diameter, giving the apparent altitude of the sun.
(5) From Inman's Tables obtain parallax for apparent altitude.
(6) Add parallax, giving altitude.
(7) From the Nautical Almanac obtain the sun's declination for Greenwich date and time.
(8) Subtract declination if declination and latitude are of same name, and add if of contrary name, giving co-latitude.
(9) Subtract co-latitude from 90°, giving latitude of place.

Problem IV.—To Find the Latitude by Observations on the Pole Star. (See Nautical Almanac, where the method is described with tables for the simplification of the work.)

Problem V.—To Find approximate True North by Observation of the Sun's Meridian Passage (without the use of special optical instruments). The principle involved in this method is that at the instant of apparent noon, at the place, the sun is either due North or due South. If, then, the apparent time at the place can be found, the direction of the shadow of a vertical post or a plumb-line will give the direction of the meridian. The method of finding G.M.T. or local time corresponding to apparent noon at the place has already been described on page 328, Problem I.

Fig. 250 illustrates the method of obtaining the direction of the sun at noon, without the aid of any special optical apparatus. A stake having been driven into the ground to mark the proposed position of the centre line of the aerial (or the mast, in the case of a M-B-T station), some device is arranged to support a plumb-line and bob so that it hangs directly over the stake. The length of this line may have to be considerable, since the accuracy of the method depends upon the distance between the observer and the line, and for this reason it is impossible to make use of the method in latitudes where the sun is very high at noon. A few minutes before the time of apparent noon a second stake should be driven in the position in which it is estimated that the shadow of the plumb-line will fall at

noon, and attached to the top of this stake is a small movable sight which can be made from a piece of sheet tin or brass. The observer now takes up a position similar to that shown in the figure and moves the adjustable sight slowly to the left or right (according to whether the sun is South or North of the place), keeping the sight always in such a position that the plumb-line exactly bisects the sun's disc. A second observer holds the watch and gives the signal at the instant which has been previously calculated to correspond to apparent noon, and the movable sight and the plumb-line are now in the meridian at the place.

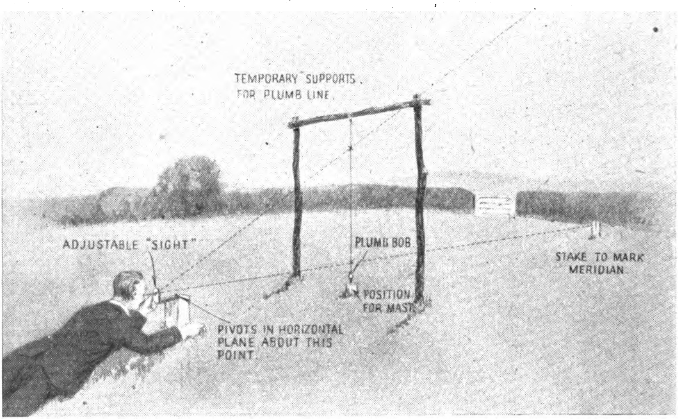

Fig. 250. *To find Direction of True North from the Sun's Meridian Passage*

The required direction may now be transferred permanently by the use of a ranging pole erected on the side of the plumb-line farthest from the sighting point.

The method, whilst having the merits of simplicity and not requiring any apparatus which is not easily obtainable, has the disadvantages that it cannot be used with any degree of accuracy in low latitudes ; it necessitates a clear sky at noon, and if any slip is made it becomes necessary to wait at least a day before the check reading can be taken. In practice, smoked glass will be required for the observation of the sun and the thickness of the plumb-line should be found by trial

beforehand. The tendency of the plumb-line to swing when there is a breeze may be reduced by allowing the bob to hang in a pail of water.

Problem VI.—To Find True North from the Sun's Azimuth. In this method of finding the direction of North, using a theodolite, the horizontal angle between the sun and some fixed point of reference, which is fairly conspicuous, is measured and the time of the observation is accurately noted. A calculation is then made to find out what was the azimuth of the sun at the instant the observation was made, and a simple process of addition or subtraction of angles will give the true bearing of the point of reference, and hence the direction of true North.

Assuming the theodolite has been located accurately over the proposed site for the centre line of the aerial system, the instrument is levelled and an observation made of the point chosen for the fixed point of reference, the horizontal scale being adjusted to read 0° when the telescope is in this position and locked. The telescope is now fitted with the solar eyepiece and adjusted until the sun's disc is visible on one side of the field of the instrument and is approaching the centre. At the instant of contact of the sun with the vertical cross wire of the telescope a signal is given to an observer with a watch, who notes the time to the nearest half-second; and similarly, when the opposite limb of the sun is just leaving the cross wire, the time is again taken and noted, care being taken not to move the instrument between the two readings. The scale reading of the horizontal angular position of the telescope relative to the fixed point of reference is also noted, this corresponding to the angle subtended at the site by the point of reference and the sun, at the time the observation is made. This completes one set of readings, but additional ones should be taken and worked out for checking purposes.

Example. Suppose that in latitude 51° 43′ 45″ North and longitude 0° 28′ 37″ East on September 10th, 1919, observations were taken of the sun's horizontal bearing from a fixed point of reference, the times of the first and second contacts being 11 h. 22 m. 20 s. and 11 h. 24 m. 35½ s. a.m. by watch, and the measured bearing of the sun 130° 10′ in a positive direction (that is, measuring from North through East), the error of the watch was 58 m. 47 s. *fast* on G.M.T. It is required to find the true bearing of the point of reference, and hence the

direction of the meridian at the place. The work may be set out as follows :—

Date, Sept. 10th, 1919.

Latitude	51° 43′ 45″ N.
Longitude	0° 28′ 37″ E.
Error of watch	58 m. 47 s. fast.

Hence G.M.T. is equal to Reading of watch *less* 58 m. 47 s.

Watch (first contact)	11 h.	22 m.	20 s.		
Watch (second contact)	11	24	$35\frac{1}{2}$		
Watch (mean of above)	11	23	28		
Watch	23	23	28	.. ..	(1)
Fast		58	47	.. ..	(2)
G.M.T. & G.D. ..	22	24	41	Sept. 9th ..	(3)
Long.		1	54	E	(4)
M.T.P.	22	26	35	.. ..	(5)
Eq. T.		+ 2	43	.. ..	(6)
A.T.P.	22	29	18	.. ..	(7)

Now find the geographical position of the sun.

Latitude = Declination	5°	16′	12″ N.	.. ..	(8)
Longitude = Hour Angle	22°	40′	30″ E.	.. ..	(9)

The azimuth may now be calculated in the same way as any great circle bearing, for details of which see Problems IX and IXa, or it may be taken from Burdwood's Tables, as described in Problem VII. Having found the azimuth by one or other of these methods, proceed as follows :—

Azimuth of sun	149°	59′ E. of N.	..	(10)
Measured bearing of sun from Pt. of Ref. ..	130°	10′ E. of N.	..	(11)
True bearing of Pt. of Ref.	19°	49′ E. of N.	..	(12)

Explanatory Notes on Above Example.

(1) Write down the time of observed azimuth of centre of the sun's disc (which is mean of times of first and second contact when these have been taken) remembering that the astronomical day begins at noon on the civil day of the same date. (See footnote, page 326.)

(2) Write down the correction for the watch.

(3) Subtract correction if watch fast, add if watch slow, giving Greenwich mean time and date.

(4) Write down the longitude of the place converted to time. (See method of converting hour angle from time to degrees on page 327).

(5) For longitude East, add (4) and (3); for longitude West, subtract (4) from (5), giving mean time at place.

(6) From Nautical Almanac take out the equation of time for the Greenwich date and time, and write down under the M.T., *with sign reversed*, since we are converting M.T.P. to A.T.P. (See definition, page 326.)

(7) Add or subtract the Eq. T. (according to reversed sign), giving the hour angle of the sun or apparent time at place.

(8) See definition, page 324).

(9) See definition, page 327). A.T.P. converted to degrees $= 337° \, 19' \, 30''$ W or $22° \, 40' \, 30''$ E. Note that this is the longitude of the sun east of the place, *i.e.*, difference of longitude, and not the longitude of the sun east of Greenwich.

(10) Write down calculated azimuth of sun, or value taken from Burdwood's Tables.

(11) Write down the measured bearing of the sun from the point of reference as read off from the horizontal scale of the theodolite when the telescope was in the position in which the observations were made.

(12) Subtract (11) from (10), adding 360° to (10), if necessary, giving the true bearing of the point of reference from which the direction of the meridian is at once obtained.

Problem VII.—To Find Compass Error from the Sun's Azimuth, using an azimuth mirror and Burdwood's Tables. When the deviation and variation of the magnetic compass are both unknown, the total compass error may be found by comparing the sun's bearing by compass, and the sun's true bearing or azimuth, the operations being exactly analogous to those described in Problem VI for finding the direction of true North on a shore station. If the sun be visible and his altitude be not greater than 38°, the compass bearing may be obtained by means of the azimuth mirror (see page 291), noting the time by chronometer.

Example. Suppose that in latitude 54° 36′ North and longitude 5° 55′ West on January 18th, 1920, the compass bearing of the centre of the sun's disc was S $3\frac{1}{2}$° E. at 9 h. 36 m. a.m. by chronometer. The error of the chronometer was 29 m. 20 s. *slow* on G.M.T. It is required to find the total compass error, and hence the true bearing of the ship's head. The work may be set out as follows :—

Date, January 18th, 1920.

Latitude	54° 36′ 00″ N.
Longitude	5° 55′ 00″ W.
Error of chronometer	29 m. 20 s. slow.

Hence G.M.T. is equal to reading of chronometer *plus* 29 m. 20 s.

Chronometer ..	21 h.	36 m.	0 s.	.. ..	(1)
Slow	0	29	20	.. ..	(2)
G.M.T. & G.D. ..	22	5	20	Jan. 17th	(3)
Long.		23	40	.. ..	(4)
M.T.P.	22	29	00	.. ..	(5)
Eq. T.		− 10	22	.. ..	(6)
A.T.P.	22	18	38	.. ..	(7)

Declination ..	20°	39′	06″ S.	(8)
Azimuth of sun		155·6°	.. .. ..	(9)
Bearing of sun by compass		176·5°	.. .. ..	(10)
Total compass error		21° W.	(approx.)or − 21°	(11)

Explanatory Notes on above Example.

(1) to (8) See same items in last example.

(9) In Burdwood's Tables find the pages corresponding to latitude 54° and *contrary* name (because latitude is North and declination South). The A.T.P. will be found on the left, expressed in civil time, and the correct azimuth is taken out from under the declination, which is to be found at the head of each column. Interpolate where necessary.

(10) Write down observed bearing of sun by compass, converting to degrees East of North.

(11) Subtract (10) from (9), expressing the total compass error in degrees East of North, either positive or negative error.

Problem VIII.—To Find True North or Total Compass Error by Observation of the Pole Star. (See Nautical Almanac for tables for finding the Azimuth of Polaris. Problems VI and VII may easily be modified for observations of Polaris, the principle involved being identical.

Problem IX.*—To find the Azimuth and Zenith Distance (Great Circle Angle and Distance).—In Fig. 251, A and B are two places on the earth's surface, the latitudes and longitudes of which are known. It is required to find the distance between A and B and the angles at A and (or) B.

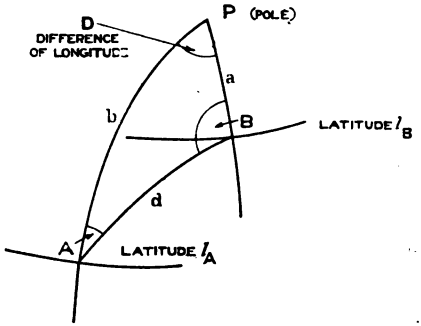

Fig. 251. *Great Circle Angle and Distance by Calculation.*

The spherical triangle APB may be solved from the equations given below, in which the following symbols have been used:—

B Place of greater latitude (*i.e.*, nearer pole).
D Difference of longitude between A and B.
l_A Latitude of A.
l_B Latitude of B.
θ A subsidiary angle which enters into the calculations.
d Angular zenith distance between A and B (see page 326)

The letters A and B have also been taken to represent the internal angles of the triangle APB at the respective places :—

$$\tan\theta = \cot l_B \cos D$$

$$\cos d = \frac{\sin(\theta + l_A)\sin l_B}{\cos\theta}$$

When A and B are on opposite sides of the Equator, l_A must be written negative ; so that $(\theta + l_A)$ becomes $(\theta - l_A)$.

Careful attention should be paid to the signs of the trigonometrical functions used, remembering that :—

* See alternative method page 344

FOR ANGLES BETWEEN	SINE	COSINE	TANGENT	CO-TANGENT
0° and 90°	+ ve	+ ve	+ ve	+ ve
90° and 180°	+ ve	− ve	− ve	− ve

and also :—

$$\sin \phi = \sin (180° - \phi).$$
$$-\cos \phi = \cos (180° - \phi).$$
$$-\tan \phi = \tan (180° - \phi).$$

For instance, when the difference of longitude, D, is greater than 90°, cos D is negative and this will make the value for tan θ also negative, indicating that θ is greater than 90°. The value of cos θ in the second equation will also have to be made negative.

If the value obtained for cos d is negative, the figure for d as taken from the tables must be subtracted from 180° to get the correct value for the angular zenith distance.

To find Linear Zenith Distance.—The linear distance between A and B is equal to :—

$$\left.\begin{array}{c}\textbf{Angular distance}\\ d\ \textbf{in degrees}\end{array}\right\}\begin{array}{l}\times\mathbf{111{\cdot}0\ Kilometres.}\\ \times\mathbf{69{\cdot}1\ Statute\ Miles.}\\ \times\mathbf{60{\cdot}0\ Nautical\ Miles.}\end{array}$$

When multiplying, the minutes and seconds must first be expressed in decimals of a degree as shown in the example below (except in the case of conversion to nautical miles when one minute of arc is equal to one nautical mile).

To Find Azimuth.

$$\sin A = \frac{\sin D \cos l_B}{\sin d} \quad \text{and} \quad \sin B = \frac{\sin D \cos l_A}{\sin d}$$

Note that since the sine of any angle ϕ is the same as the sine of $(180° - \phi)$, it follows there will be two solutions to each of the above expressions for the angles at A and B respectively. Since, however, B is north of A (having been made so), the angle B is always greater than a right angle and the angle A always less.

The solution of these equations is most easily accomplished by the use of logarithms and may conveniently be set out

as in the following example, which is given without further explanatory notes.

Example.—Suppose that a D.F. station has been erected near the Hook of Holland, in lat. 52° 00′ 00″ N., and long. 4° 08′ 00″ E., and that it is required to know the true bearing and great circle distance of the W/T station at Seaforth in lat. 53° 28′ 14″ N., and long. 3° 00′ 42″ W.

	PLACE	LONG	LAT.
A	Hook	4° 08′ 00″ E.	52° 00′ 00″ N.
B (nearer Pole)..	Seaforth ..	3° 00′ 42″ W.	53° 28′ 14″ N.

D = Diff. Long. = 7° 08′ 42″

log cot. l_B .. 9·869676
log. cos. D*.. 9·996615
(Add) log. tan. θ *.. 9·866291
θ = 36° 18′ 58″

l_A* .. 52° 00′ 00″
θ .. 36° 18′ 58″
$(\theta + l_A)$ .. 88° 18′ 58″

log. sin. $(\theta + l_A)$ 9·999812
log. sin. l_B .. 9·905014
(Add) 9·905914
log. cos. * .. 9·906207
(Subtract) log cos d * .. 9·998619
d = 4° 34′ 00″

Great circle distance in statute miles $= d \times 69{\cdot}1$
$= 4{\cdot}566° \times 69{\cdot}1$
$= 315{\cdot}55$

To find angle A :—

log. sin. D.. 9·094754
log. cos. l_B.. 9·774689
(Add) 8·869443
log. sin. d .. 8·901017
(Subtract) log. sin. A.. 9·968426
A = 68° 24′ 56″

True bearing of Seaforth = (360° — 68° 24′ 56″)
= 291° 35′ 04″ East of North.

*Note carefully instructions regarding signs. (Pages 341 and 342).

Problem IXa. To Find Great Circle Angle (Alternative Method).—In Fig. 251, if the true bearing only of B from A (or *vice versa*), be required, and not the great circle distance, there is a rather shorter method of solving the triangle APB by means of the equations given below, in which the symbols used are the same as in the previous case, namely :—

B The place of greater latitude (*i.e.*, nearer pole).
l_A Latitude of A.
l_B Latitude of B.
D Difference of longitude between A and B.

The letters A and B are also taken to represent the internal angles of the triangle APB at the respective places.

$$\tan \frac{B + A}{2} = \frac{\cos \frac{l_B - l_A}{2} \cot \frac{D}{2}}{\sin \frac{l_B + l_A}{2}}$$

$$\tan \frac{B - A}{2} = \frac{\sin \frac{l_B - l_A}{2} \cot \frac{D}{2}}{\cos \frac{l_B + l_A}{2}}$$

From the first of these two equations, is found the value of $\frac{B + A}{2}$ and from the second, $\frac{B - A}{2}$, the sum and difference of which give respectively, B and A.

When A and B are on opposite sides of the equator, l_A, (the latitude of A) must be written negative. For instance, if B is in latitude 50° North, whilst A is in 15° South, then :—

$$\frac{l_B + l_A}{2} = \frac{50^\circ - 15^\circ}{2} = 17^\circ\ 30'$$

and $$\frac{l_B - l_A}{2} = \frac{50^\circ + 15^\circ}{2} = 32^\circ\ 30'$$

Problem X.—To Plot a Great Circle on a Mercator's Chart. In Chapter 4, on page 112 *et. seq.*, when comparing the properties of the Mercator's and gnomonic charts, reference was made to a method of calculating the intersection of the great circle, between any two points, with the intervening meridians, thereby enabling the great circle track to be plotted on a Mercator's or any other chart. The great circle which

was taken as an example in Chapter 4, was between the points A 25° N., 15° W., and B 45° N., 15° E., and the method of finding the intersections of this great circle with the meridians 10° W., 5° W., prime meridian, 5° E., and 10° E., is given below as an example of the method.

In Fig. 252 ABV is the great circle and V is the vertex or point of greatest latitude, which may or may not lie between A and B. In this example it lies to the eastward of B. The points A_1, A_2, etc., are the required intersections with meridians.

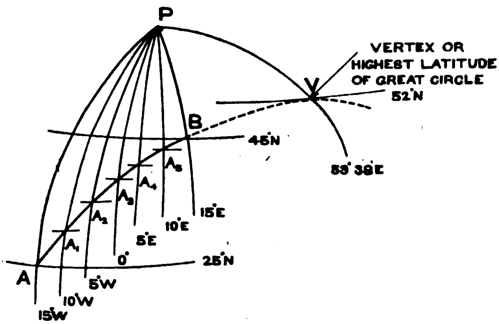

Fig. 252. Calculation of Intersections of Great Circle AB with Meridians in order to plot Great Circle on Mercator's Chart.

It is necessary first to solve the triangle APB, in order to find the values of the angles at A and B. This process has been described in the previous problem, and when applied to this example gives A=42° 47′ and B=60° 31′ 30″.

The latitude of V must next be found as follows :—

In the spherical triangle APV,

$\tan P = \cot A \operatorname{cosec} l_A$ where l_A = lat of A

$\cos l_V = \sin A \cos l_A$ where l_V = lat of V.

Solving these equations, we have :—

Angle A = 42° 47′	.. log cot A	10.03364	.. log sin A	9·83202
l_A = 25° N.	.. log cosec l_A	10.37405	.. log cos l_A	9·95728
Add	.. log tan P	10.40769	.. log cos l_V	9·78930

whence P=68° 38′ and l_V=52° N.

Now find the longitude of V. The angle VPA=68° 38′, and since the longitude of A is 15° W., long. V=68° 38′−15° =53° 38′ E.

The latitudes of intersection of any meridian A_1, A_2, etc., can now be found by solving the triangles PVA_1, PVA_2, etc., in which we have

$$\cot l_{A1} = \cot l_V \sec VPA_1, \text{ etc., etc.,}$$

and this is most simply done by tabulating the work as shown below.

The angles VPA_1, VPA_2, etc., may be written down, remembering that the longitude of V is 53° 38′ E., thus :—

Angle VPA corresponding to meridian 10° W. is 53° 38′+10° =63° 38′, and so on.

Meridians	10° W.	5° W.	0°	5° E.	10° E.
VPA_1, VPA_2 etc.	63° 38′	58° 38′	53° 38′	48° 38′	43° 38′
log cot l_V (52°)	9.89281	9.89281	9.89281	9.89281	9.89281
log sec VPA_1, VPA_2, etc. ..	10.35251	10.28357	10.22698	10.17988	10.14040
log cot l_{A1}, l_{A2}, etc. ..	10.24532	10.17638	10.11979	10.07269	10.03321
Latitudes of A_1, A_2, etc. ..	29° 37′	33° 40′	37° 12′	40° 14′	42° 49′

PROBLEM XI. To Draw a Gnomonic Chart (Graticule).—In Chapters 4 and 5, the characteristics and uses of the gnomonic chart have been described, and on page 108 a series of gnomonic graticules were shown, simplified diagrams of two of these being illustrated in Figs. 103 and 123. For the purpose of demonstrating the construction of such a graticule, it is proposed to reproduce all the essential features in the preparation of "Chart F" (Fig. 103), of the above-mentioned series.

The particulars of the chart are as follows :—

Northern limit of latitude .. .. .. 62° 30′
Southern limit of latitude .. .. .. 47° 30′
Scale of Chart .. .. .. 25 naut. miles = 1 in.
Point of contact at the centre of the sheet.

The chart thus includes 15 degrees of latitude and with a scale of 25 nautical miles to the inch, the size of the sheet required will be $\frac{15 \times 60}{25} = 36$ inches (approx.), so that a sheet 40 inches by 40 inches will leave a suitable margin.

A mathematical analysis of the gnomonic projection will be found in the Admiralty Manual of Navigation (83), but

the requisite information is contained in a set of formulæ*, which are numbered 1 to 7 in the ensuing instructions, and in which the following symbols are used :—

C Point of Contact.

l_C Latitude of Point of Contact.

l_a Latitude of bottom of chart.

l_b Latitude of top of chart.

G Difference of longitude between Point of Contact and any given meridian.

R Radius of the Earth, reduced to scale of chart.

C′ Point of intersection of $a'\,b'$ by line through C perpendicular to $a'\,b'$.

l_c' Latitude of C′.

l_d Latitude of parallel through the points d, d', d'', etc.

It should be noted that although the preparation of the data and the instructions for drawing the chart are dealt with together in the following notes, the whole of the calculations may actually be made before any drawing is done, and the advantages of this plan are mentioned later (Page 352.)

The line $a\,b$ is first drawn to represent the meridian of the point of contact and in the case under consideration this will be at the centre of the sheet, as shown diagrammatically in Fig. 253.

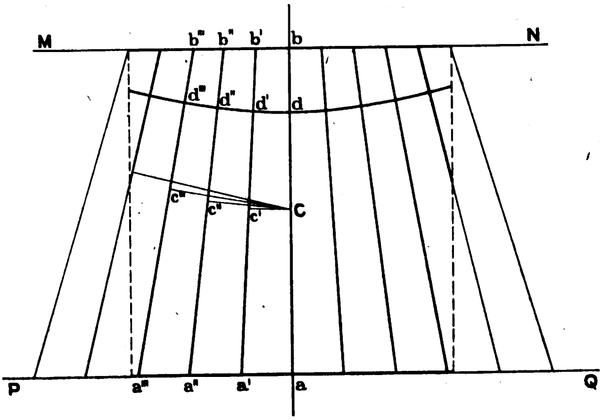

Fig. 253. *Construction of a Gnomonic Graticule.*

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The length of the line $a\,b$ is given by :—

$$a\,b = \text{R tan } (l_b - l_C) + \text{tan } (l_C - l_a) \quad . \quad . \quad . \quad . \quad . \quad 1$$

and the point C must be chosen such that :—

$$\left.\begin{array}{l} b\,\text{C} = \text{R tan } (l_b - l_C) \\ \text{C}\,a = \text{R tan } (l_C - l_a) \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

In the present case, since the point of contact is at the centre of the sheet, the line $a\,b$ is bisected at C and the length $a\,b$ is therefore given by :—

$$a\,b = 2\text{R tan } 7^\circ\ 30'$$

The radius of the earth (20,890,550 feet), reduced to the scale of the chart is given by $\dfrac{\text{Radius in feet}}{\text{Scale in feet per inch}} = \dfrac{20890550}{25 \times 6080}$ and the remainder of the working, using logarithms, is set out below without further comment.

log. 20890550	7·319948
log. 25	1·397940
log. 6080	3·783904
	5·181844
log. R	2·138104

To find $a\,b$:—

log. 2	10·301030
log. R	2·138104
log. tan. 7° 30′	9·119429
log. $a\ b$	1·558563

$a\,b = 36{\cdot}188$ inches.

Through a and b, draw PQ and MN, at right angles to $a\,b$.

The distances $a\,a'$, $a\,a''$, etc., and the corresponding values of $b\,b'$, $b\,b''$, etc., must next be found in order to draw the meridians, but before beginning on this it is necessary to decide upon a value for the difference of longitude between successive meridians drawn on the chart. This will depend solely on the accuracy desired, the closer the meridians are together, the greater the number of points available for plotting the curves representing the parallels of latitude. For instance, at the latitude of the point of contact, that is to say 55° N., a degree of longitude is $60 \times \cos.\ 55^\circ = 34{\cdot}2$ nautical miles in length, which is $\dfrac{34{\cdot}2}{25} = 1{\cdot}4$ inches on the chart. The spacing can therefore be taken as 30 minutes, which will

give 0·7 inches between meridians at the centre of the chart and not more than about an inch at the lower margin.

The distances *a a′*, *a a″*, etc., and *b b′*, *b b″*, etc., are found from the following :—

$$a\,a' = [\mathrm{R}\cos l_a \sec (l_C - l_a)] \tan \mathrm{G}. \qquad . \quad . \quad . \quad . \quad . \quad 3$$

$$b\,b' = [\mathrm{R}\cos l_b \sec (l_b - l_C)] \tan \mathrm{G}. \qquad . \quad . \quad . \quad . \quad . \quad 4$$

The factor contained in the square bracket, by which tan G has to be multiplied, is seen to be a constant quantity in each of the above expressions, and it will simplify the working out of the values of *a a′* and *b b′* for the various values of G, if we find the logarithm of the quantity in the square bracket, in each case, and add this to log. tan. G., the work being set out in tabular form as in Table I.

Thus, *a a′* = R cos 47° 30′ sec. 7° 30′ tan G.

log. R	2·138104
log. cos 47° 30′	9·829683
log. sec. 7° 30′	10·003731
Log of expression in bracket.	1·971518

(See Table I, Col. 3.)

and *b b′* = R cos 62° 30′ sec. 7° 30′ tan G.

log R	2·138104
log cos 62° 30′	9·664406
log sec 7° 30′	10·003731
Log of expression in bracket.	1·806241

(See Table I, Col. 5.)

TABLE I.

1 G	2 Log tan G	3 Col. 2 + 1.971518	4 Antilog. Col. 3 = *a a′* in inches	5 Col. 2 + 1.806241	6 Antilog. Col. 5 = *b b′* in inches
0° 30′	7·940858	9·912376	0·8173	9·747099	0·559
1° 00′	8·241921	0·213439	1·634	0·048162	1·117
—	—	—	—	—	—
11° 00′	9·288652	1·260170	18·204	1·094893	12·442
—	—	—	—	—	—
16° 00′	9·457496	—	—	1·263737	18·354

The values in columns 4 and 6 will now enable the distances *a a′*, *a a″*, etc., and *b b′*, *b b″*, etc., to be scaled off along the lines MN, PQ, and the meridians *a′ b′*, *a″ b″*, etc., drawn.

The length, in inches, of $C\,d$, along the centre meridian, in which d is the point of intersection on $a\,b'$ of a parallel of latitude l_d, is found from :—

$$Cd = R \tan (l_d - l_C) \qquad 5$$

The work may again be tabulated as in Table II, parallels being taken every 30 minutes of arc, as in the case of meridians. The constant quantity 2·138104, in Col. 4, is the logarithm of R.

TABLE II.

1	2	3	4	5
l_d	$l_d - l_C$	Log tan $(l_d - l_C)$	Col. 3 +2·138104	Cd in inches
62° 30′	7° 30′	9·119429	1·257533	18·094
62° 00′	7° 00′	·089144	·227248	16·874
61° 30′	6° 30′	·056659	·194763	15·66
—	—	—	—	—

Perpendiculars must next be dropped from the point C on to all the meridians, intersecting them at the points c', c'', etc. It should be noted that these points c', c'', etc., do *not* lie on the same parallel, and the actual latitudes of these points are next found from :—

$$\tan l_c' = \tan l_C \sec G. \qquad 6$$

Table III, below, shows the work set out in columns 1 to 4, the constant which is added in column 3 being the value of log. tan. l_C = log. tan 55° = 10·154733.

(The last two columns contain data which is required later but which may very conveniently be tabulated at this stage. The constant which is added in column 6 is explained below.)

TABLE III.

1	2	3	4	5	6
G	Log. sec. G	Col. 2 +10·154733	l_c'	Log. sin. l_c'	Col. 5 +2·224740
0° 30′	10·000017	10·154790	55° 00′ 06″	9·913370	2·138110
1° 00′	·000066	·154839	55° 00′ 15″	·913387	·138127
1° 30′	·000149	·154922	55° 00′ 30″	·913409	·138149
—	—	—	—	—	—

The final problem consists in calculating, from the following :—

$$C'd' = [R \operatorname{cosec} l_C \sin l_c'] \tan. (l_d - l_c') \qquad 7$$

the distance in inches from the point C′, of the intersections

of all the parallels. This must be done for each meridian, but it will be seen that the factor in the square bracket is a constant quantity for any given meridian and this series of constants are the values found in Col. 6 of Table III above.

Thus Table III, Col. 5 gives the value of log. sin. l_c' for varying values of latitude and in Col. 6 is added to this a constant equal to :—

log. R	..	2·138104
log. cosec. l_C	..	10·086636
		2·224740

A set of tables must now be made for successive values of G (that is, difference of longitude from the meridian of the point of contact). From the symmetry of the present chart, it will only be necessary to make calculations for one half of the sheet. Starting with a value of G = 0° 30′, we get :—

TABLE IV.

G = 0° 30′

1	2	3	4	5
l	$(l_d - l_c')$	Log. tan. $(l_d - l_c')$	Col. 3 +2·138110	Antilog. Col. 4 = C′ d'
62° 30′	7° 29′ 54″	9·119332	1·257442	18·09
62° 00′	6° 59′ 54″	·089039	·228149	16·87
61° 30′	6° 29′ 54″	·056546	·194656	15·656
—	—	—	—	—
—	—	—	—	—

TABLE V.

G = 1° 00′

1	2	3	4	5
l_d	$(l_d - l_c')$	Log. tan. $(l_d - l_c')$	Col. 3 +2·138127	Antilog. Col. 4 = C′ d′
62° 30′	7° 29′ 45″	9·119185	1·257312	18·085
62° 00′	6° 59′ 45″	·088883	·227010	16·865
61° 30′	6° 29′ 45″	·056379	·194506	15·65
—	—	—	—	—
—	—	—	—	—

Table VI is then made out for G = 1° 30′, and so on, the constants in Column 4 being obtained in each case from the last column of Table III.

Table I, when completed, will show the extent to which it is necessary to carry these calculations. For instance it is found that the limit of longitude on either side of the centre meridian, along the upper margin of the chart (Lat. 62° 30′) is 16 degrees, whilst along the lower margin (Lat. 47° 30′), it is only 11 degrees. The vertical margins of the finished sheet are shown as dotted lines in the diagram of Fig. 253. This means that from the table representing G = 11° 30′, to the table representing G = 15° 30′, the tables may be made gradually shorter, neglecting the portions of the meridians not included in the finished sheet. A glance at Fig. 253 will make this point clear.

Hints on Drawing the Chart. Good quality cartridge paper must be used for the drawing and the room in which the work is carried out should be kept at an even temperature and humidity. The latter factor is an important one, as if the drawing is started on a dry day and not completed, it may be found on resuming the work on a subsequent damp day, that the paper has shrunk and rendered the whole thing useless, as none of the calculated data will now fit in with the new dimensions. Pasting the edges of the paper on to a drawing board is not a very satisfactory solution as it is difficult to avoid crinkling or tearing the paper, due to expansion and shrinking, and the only safe method is to prepare all the data beforehand and to choose a dry day for the drawing and complete it as rapidly as possible. To ensure complete accuracy, check measurements should be made on the drawing at the time it is lithographed (if this is done) to see that it has not shrunk. It may be pointed out by the way of warning that the simple process of tracing the chart and making "blue prints" is practically out of the question as the printing papers used (or at any rate many of the commercial brands), shrink about ⅛ inch per foot in one direction and very much less than this in the direction at right angles. As a result of this, the finished 40″ square chart will be distorted in one direction to the extent of about ⅜″ to ½″.

The instruments required for the drawing consist of an accurate straight-edge, beam compasses, the usual drawing instruments and a moderately flexible steel rule at least as long as the maximum dimension of the chart, and which is graduated in inches, tenths and twentieths of an inch. Although it is not feasible to measure to a thousandth of an inch from a rule graduated in twentieths, yet it will be found that with

the aid of suitable lighting and a small magnifying glass, the nearest hundredth can be estimated quite easily and greater accuracy than this is possible after a little practice. It is therefore worth the while to calculate all dimensions to the third place of decimals. This extreme accuracy may seem rather unnecessary in view of the fact that the average D.F. is only reliable to within say about a quarter to half a degree, but experience shows that comparatively slight negligence in drawing the chart may lead to azimuthal errors quite comparable with experimental errors.

Having drawn the centre meridian and marked the positions of the points *a*, *b* and C, a geometrical construction should be used to obtain the lines MN and PQ at right angles to *a b*. Set squares and T square are not reliable for this, and it requires very careful work with beam compasses to obtain points through which to draw MN and PQ such that check measurements between M-P and N-Q are equal to within the thickness of a pencil line.

The dropping of the perpendiculars from C on to the meridians $a\ a'$, $b\ b'$, etc., must also be performed in the same way by geometrical construction, with the possible exception of the meridians very close to the centre one. Having obtained all the points C, C$'$, C$''$, C$'''$, etc., a flexible steel rule should be placed on the drawing so as to pass through the points and if any of them do not appear to lie on the smooth curve, their positions should be checked and corrected.

When all the points on the meridians have been scaled off it is advisable to draw a smooth curve to represent each parallel, using the flexible steel rule and again any point which is not on this curve should be checked. A number of such slight errors always occur amongst a mass of tabulated calculations.

At this stage a few check bearings should be measured from the chart, the correct values of which have previously been calculated and provided these agree to within a few minutes of arc, the chart can be inked in and completed.

The parallels need not be inked in as curves. If straight lines are drawn between successive meridians, on top of the pencil curve which has already been drawn, the resulting line cannot be distinguished, by eye, from a curve, and it is easier to draw and avoids the chances of smudging when using a flexible rule. The rule is also rather difficult to manipulate and needs at least two assistants.

For convenience in the use of the chart, it will be advisable to have lines drawn for every 10 minutes of arc, which means that two lines will have to be drawn in each of the spaces between the meridian on the chart and similarly between the parallels. This sub-division entails nothing more than some rather tedious work with a small pair of spring bow compasses. As before, the parallels can be drawn as a succession of straight lines between the points on the meridians

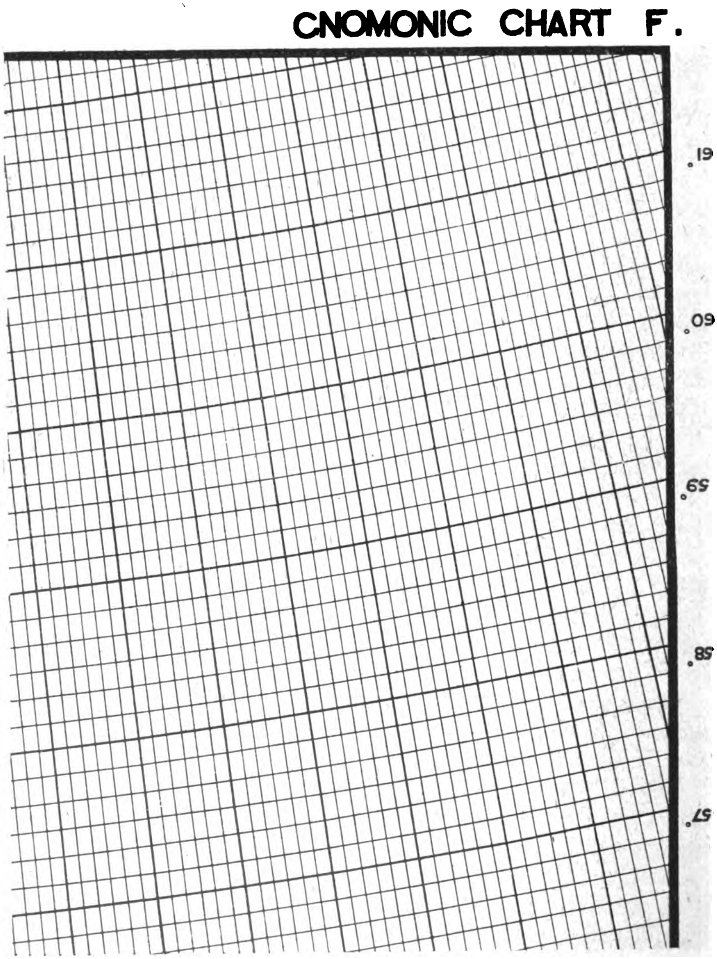

Fig. 254. *Portion of Completed Graticule.*

and having drawn a border the finished chart will now appear as in Fig. 254, which is a photograph of a corner of the actual chart (reduced to rather less than one-third full size). As already mentioned (page 108), it is convenient to mark the scale of latitude with the numbers upside down in the right-hand margin and make use of the left-hand margin only. By doing this the chart may be turned upside down for use in southern latitudes and the figures in the left-hand margin will still be the right way up.

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Printed by Sanders Phillips & Co., Ltd., Chryssell Road, S.W.9

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